A.5.2 Control procedure

Regarding the control procedure within manufacturing and construction, a distinction can be made between the following:

— Production control, which is control of a production process; the purpose of this control is to steer a production process and to guarantee an acceptable result;

— Conformity control, which is control during or after the construction process or of the result of a production process; the purpose of this control is to ensure that the result of a production process conforms to the given specification.

NOTE In case of construction works, conformity control is often best performed before or during the construction process, e.g. in case of placement of reinforcement.

As both control procedures have different objectives, methods for performing either production or conformity control should in general also be differentiated.

The control procedure, as well as possible non-conformity actions, should be specified in advance.

A.5.3 Control criteria and acceptance rules

Control can be total or statistical. If the control is total, every produced unit is inspected. The acceptance rules imply that a unit is judged as being good (accepted) or bad (not accepted). Normally, the criteria, if they are quantitative, refer to given tolerances.

With respect to compliance control, a distinction can be made between the following:

— Control by attributes, when a unit is in a state of ‘good’ or ‘bad’ and the decision yields ‘accepted’ or ‘not accepted’.

— Control by variables, when a unit can be evaluated according to a scale of measurement.

A statistical control procedure generally consists of the following parts:

— batching the products;

— sampling within each batch;

— testing the samples;

— statistical judgement of the results;

— decision regarding acceptance.

A batch should be such that it can be regarded as homogeneous (both in space and time) with regard to the properties which are the subject of the control. Batching and sampling of the products should be executed according to a specified sampling plan. The judgement of the results should normally be made with regard to either

— a given level of confidence and/or a given interval of confidence,

— a specified performance of the operating characteristic associated to the compliance control, either in terms of acceptance probabilities at the acceptable quality level (AQL) and limiting quality (LQ) or in terms of a specified value of the average outgoing quality limit (AOQL), and

— by applying Bayesian techniques.

In case of control by attributes, the acceptance rules are specified as an acceptable number of defectives c in a random test sample of size n. In case of control by variables, it is verified whether a compliance function consisting of one or more test statistics based on n random test samples lies within an acceptable region. The acceptable region can consist out of one or more boundaries.

A.5.4 Control process

Distinction can be made between the following different control steps, depending on the person or organization supervising the control:

— individual self-checking;

— internal control;

— acceptance control handled by the project management;

— independent external party control of design and/or execution;

— control and supervision by the client's organization.

The choice of the required control steps mentioned shall depend on the required quality inspection level, which can depend on a quality level differentiation (see A.6).

There often exists an additional control, such as that initiated and executed by the public authority and based on building laws and/or codes.

Internal control is executed in the same office, factory, or workshop where the work which is the object of the control is carried out. However, the work and the control are executed by separate bodies.

If a control process consists of several steps, it is important for the final result that the activities of these steps, as far as possible, are mutually independent, in a statistical sense; otherwise, the efficiency of the control will decrease.

In many cases, it is necessary to set up a control plan which is part of the quality plan according to A.4.

A.5.5 Filtering effects of quality control

In general, quality control of an entity has a favourable effect on its characteristics due to the fact that the existence of quality requirements (such as quality management, production, and compliance control) compels one to deliver high-quality products. This favourable filtering effect has an influence on the uncertainty representation (Clause 6), probability-based decision making (Clause 7), and structural robustness assessment (Annex F). Hence, the beneficial effect of quality control might be included in risk-based approaches.

One or more aspects of the quality control, i.e. quality management, quality assurance, or quality control (either by production control or compliance control), can be taken into account in the uncertainty representation by using Bayesian techniques. In case of conformity control, operating characteristics can be considered as a likelihood function in case of Bayesian updating. In the latter case, updating of the parameters or the hyperparameters of probabilistic models can be calculated as follows:

$$f''_{\bar{B}}(\beta)=\frac{P_a(\beta)f'_{\bar{B}}(\beta)}{\int P_a(\beta)f'_{\bar{B}}(\beta)\;d\beta} \tag{A.1}$$

with $\boldsymbol{\beta}$ a vector with parameters or hyper-parameters of a probabilistic model of the statistical population to be updated, $f'_{\bar{B}}(\beta)$ and $f''_{\bar{B}}(\beta)$ the prior resp. posterior distribution function of the vector $\boldsymbol{\beta}$, and $P_a(\boldsymbol{\beta})$ the operating characteristic of the conformity control, i.e. the probability of acceptance of a population characterized by a probabilistic model with parameters or hyperparameters $\boldsymbol{\beta}$.

A tentative indication of the quality management activities, for which such a Bayesian updating of characteristics of entities might be considered, is indicated in Table A.1.

In case the quality control is taken into account in the uncertainty representation and/or probability-based decision making, it should however always be ensured that the quality control will be adequately executed.

In case of the application of new materials or construction methods, intensified quality control together with a quantification of its influence on risk-based or reliability-based methods can justify a risk-based or reliability-based design when incorporating material and model uncertainties. In case of lack of prior information, vague priors or low-informative expert judgment based priors can be used in the above-mentioned Bayesian approach.

A.6 Quality level differentiation

Three possible quality levels (QL) are shown in Table A.2. The quality levels can be linked to the quality management, quality assurance, and quality control measures described in A.3, A.4, and A.5, respectively. All three components (quality management, quality assurance, and quality control) should be considered together when assigning a quality level.

The quality level differentiation can directly be linked to the consequence classes described in F.1. As such, they can directly be related to a differentiation in structural applications.

NOTE This quality level differentiation can also be related to a differentiation in reliability index β which takes account of accepted or assumed statistical variability in action effects, resistances, and model uncertainties.

In case of buildings, engineering works and engineering systems where high consequence for loss of human life or economic, social, or environmental consequences are involved, that is, public buildings where consequences of failure are high (e.g. a concert hall, grandstand, high-rise building, critical bearing elements, etc.), a quality level QL3 has to be applied. The choice of the required quality level can be based on reliability-based methods.

Table A.2 — Quality levels (QL)

Quality Level (QL)	Consequence class (see Annex F)	Description	Control organism for specification of requirements and checking
QL1	1–2	Basic quality level	Self-control: specification of requirements for quality management, assurance, and control, as well as the checking performed by the person who has prepared the stage of the life cycle involved.
QL2	3	Increased quality level	Specification of requirements for quality management, assurance, and control, as well as the systematic checking performed by self-control, as well as by different persons than those who prepared the stage of the life cycle involved and in accordance with the procedure of the organization. Increased effort with respect to supervision and inspection during the construction of the structural key elements.
QL3	4–5	Extensive quality level associated to extended measures for quality management, inspection, and control	Besides self-control and systematic control, independent party control shall also be executed: specification of requirements for quality management, assurance, and control, as well as the checking performed by an organization different from that which has prepared the stage of the life cycle involved. Intensive supervision and inspection during construction of the structural main bearing system by well-qualified people with an expert knowledge (e.g. with respect to design and/or execution of structures).

Annex B
(informative)

Lifetime management of structural integrity

B.1 Introduction

Structural integrity management (SIM) is a continuous lifetime process which should ensure, with an appropriate degree of reliability that a structure satisfies the aims and objectives specified in 4.2.1 over its entire working life, from construction to demolition. The process is essential since even if a structure has been designed and constructed according to the above aims and objectives, there is no guarantee that it will continue to fulfil them in the future.

Integrity of a structure can be impaired with time by degradation and damage caused by various actions and environmental influences, its use and/or loading can be changed, or its service life might need to be extended beyond the design working life. In addition, there can be errors in design and construction. Under such circumstances, inspections and maintenance are essential for detecting unexpected flaws, damage, and degradation. They are to be followed by an appropriate evaluation and possible repair or upgrading which help the structure to maintain its integrity. The necessity to carry out such actions over the service life of the structure should be taken into account during its design and construction.

NOTE The term inspections include any activity aiming to collect information about the performance of structures over their service life and thus also should be understood to include what is commonly referred to as monitoring.

In the following, a generic SIM process will be described in the context of a risk/reliability-based approach. The main phases of the process such as data collection, evaluation, development of inspection strategy and programme will be considered. Special attention will be paid to updating of structural reliability assessment using new inspection data.

B.2 Main phases of structural integrity management process

A SIM process includes the following phases (ISO 19902):

- Data collection, in particular by inspection.
- Evaluation of data followed, if necessary, by structural assessment and remedial actions.
- Development of inspection strategy.
- Development of a detailed inspection program.

The phases of the process are shown in Figure B.1 and considered in more detail further in the annex.

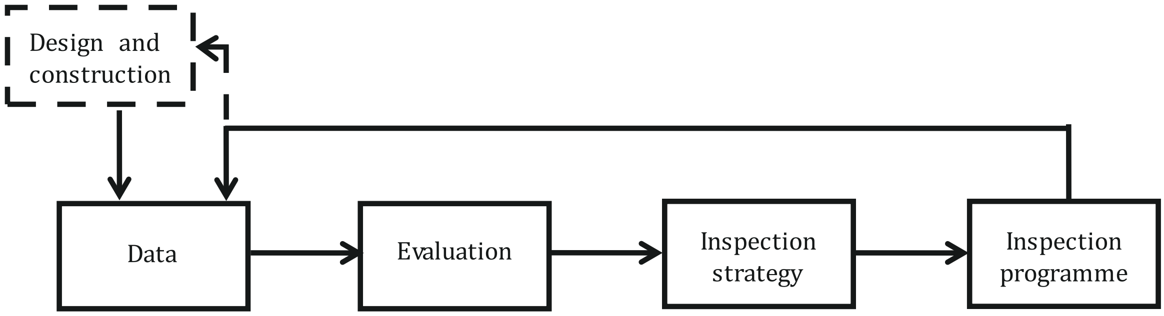

Figure B.1 — Phases of a structural integrity management process

The dashed arrow in Figure B.1, which goes back from a SIM process to design and construction, stresses the importance of planning this process during the design of a structure. This includes identifying components of the structure, which are critical for its integrity and can be damaged and/or deteriorate over its service life. The design should ensure that there is a reasonably easy access to such components for their inspection and maintenance. It should also be considered that such components might need to be repaired or replaced over the structure service life. Thus, as far as it practicable, the design should allow performing these actions with relative ease. If it becomes clear during initial planning of the SIM process that the above conditions are not met changes might need to be made in the original design.

B.3 Data collection

Up-to-date data on the structure are essential for a SIM process. The data should include information on the structure original design, construction, inspections, structural assessments, modifications, changes of use, strengthening, repairs, and accidents. In some cases, information about structural parameters such as strain, stress, deflection, vibration, temperature, pressure, etc. can be collected continuously through monitoring. Monitoring can be economically justified on the basis of the cost–benefit analysis of the structure with and without monitoring. All the collected data should be stored by the owner or operator throughout the entire service life of the structure and transferred to a new owner if the change of ownership takes place.

B.4 Evaluation and structural assessment

B.4.1 Data evaluation

When new information on the structure becomes available, all relevant data need to be evaluated using initially engineering judgement and then, if found necessary, more detailed analysis in order to determine whether structural assessment or updating the inspection strategy is needed. Note that decision about updating the inspection strategy can be made without detailed structural assessment, while structural assessment might not necessarily lead to updating the inspection strategy.

An assessment of a structure is usually required when either

a) purpose/use of the structure has changed compared to the original design or previous assessment, or

b) properties of the structure have deviated from those adopted in the original design or previous assessment.

Situations when the purpose/use of the structure has changed include

— increase in loading/actions,

— change in use,

— extension of the structure life beyond its design working life, and

— increase in the target reliability level due to increased importance of the structure to society.

Situations when properties of the structure have deviated include

— design error,

— defects or damage of the structure during construction,

— degradation of the structure (e.g. due to corrosion, fatigue, etc.),

— structure has been damaged by an accidental event or overload,

— modification of the structure, and

— change in design requirements due to revision of design codes.

Carrying out a structural assessment can require collection of more data by further inspection.

It can be decided without an assessment that updating the inspection strategy is needed when, e.g. there is evidence that a degradation process takes place but no associated damage has yet been observed, environmental conditions have changed, similar structures have exhibited unsatisfactory performance, etc.

B.4.2 Structural assessment

An assessment should determine whether a structure fits intended purposes through the performance indicators listed in 4.1 of the standard or remedial measures are needed. In the assessment exposure events, vulnerability and robustness of the structure are considered in line with 4.2.2, i.e. in the same way as in structural design. However, there is a fundamental difference between the assessment and design situations with regard to uncertainties.

In design, uncertainties arise from the prediction a priori of load and resistance parameters of a structure, which does not exist at that time. These uncertainties represent the variability of a large population of structures caused mainly by the differing quality of materials and construction practices and variability of site-specific loads. They are assessed based on given specifications for manufacturing and construction of the structure along with generic data on statistical characteristic of loads and environmental parameters.

In assessment, an existing structure can be inspected/tested so that load, resistance, and environmental parameters can be measured on-site. However, this does not mean that the uncertainties can be completely resolved because of uncertainties associated with in-service inspection/testing. It is essential to remember that inspection methods have a limited resolution. Thus, inspection results can only be considered as indicators of the real condition of a structure. The issue is to which degree the indication of a certain condition is related to the real condition. For this purpose, the concept of the Probability of Detection (PoD) is very useful. PoD provides a quantification of the quality of inspection methods through the probability of detection of a defect of a given size or extent.[1]

Uncertainties associated with in-service inspection/testing include

— measurement error,

— inherent variability of a measured parameter,

— model uncertainty when a parameter of interest cannot be measured directly so that a relationship between it and the corresponding measured parameter is needed, and

— statistical uncertainty due to a limited number of measurements.

Uncertainties associated with inspection should be taken into account in a structural assessment. This can be done by the use of probabilistic methods either explicitly in reliability analysis or for updating the characteristic and design values of basic variables. Because of different nature of uncertainties associated with the design and assessment situations, applicability of the characteristic values of basic variables and the partial safety factors from design codes shall be carefully investigated.

A conservative design does not usually lead to a significant increase in structural cost, while a conservative assessment can result in unnecessary and costly repairs or replacement. Thus, in order to reduce the model uncertainty, more refined structural models (e.g. finite element models) compared to those in design codes can be used for the assessment of existing structures.

The process of collecting information, assessing structural performance through analysis and devising repair and strengthening activities is a decision process which aims to identify the most effective investigations and modifications required to satisfy new requirements to the use of the structure and/or to remove any doubts regarding its current condition and future performance. It is important that this process is optimized with due consideration of the total service life costs of the structure.

A generic assessment process can be organized in accordance to the flowchart shown in Figure B.2 (ISO 13822:2010, Annex B). Further information on structural assessment can be found in ISO 13822.

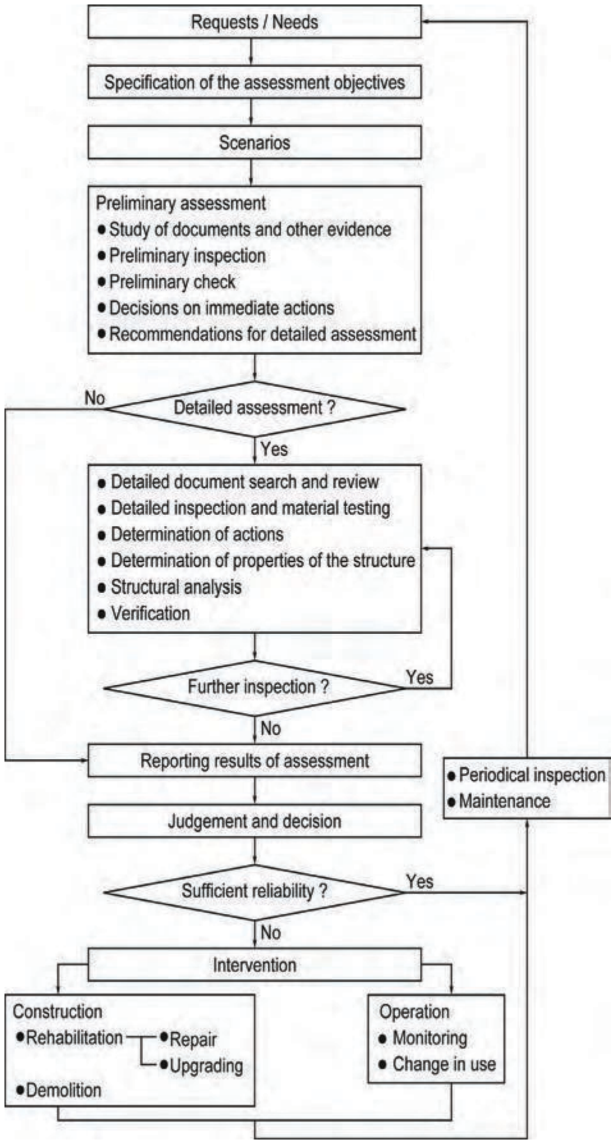

Figure B.2 — Flowchart for a generic assessment process

B.4.3 Updating information

Updating information on properties of a structure is an essential part of an assessment. Two complementary approaches to updating can be considered:

a) Checking performance of the whole structure (or its structural elements) by proof-load testing or by using information about its past performance.

b) Collecting data about individual basic variables by conducting in-service inspections. Updating previously available uncertain information using new inspection data are usually done by a Bayesian method. Updating can be carried out using either a single observation — event updating or multiple observations — distribution updating. In the first case, a parameter controlling “failure” is measured. If the corresponding observation of the safety margin H [= $g(X)$], is greater than zero, the updated probability of failure is then:

$$p_{\mathrm{f}}^{U} = p\left[g(X) \le 0 \mid H > 0\right] = \frac{p\left[g(X) \le 0 \cap H > 0\right]}{p\left[H > 0\right]} \tag{B.1}$$

Efficiency of such updating depends on how closely the measured parameter is related to failure.

To illustrate updating in the second case consider a basic variable X whose probability density function depends on a set of parameters $\boldsymbol{\theta}$ (e.g. mean and standard deviation). Denote a prior distribution of $\boldsymbol{\theta}$ as $f'_{\theta}(\theta)$. This distribution is based on information available on $\boldsymbol{\theta}$ before an in-service inspection. It should be noted that even if the prior information is rather poor, it is very important to take it into account as it could reduce significantly uncertainty on φ and, subsequently, on X. Assume that $\mathbf{x}' = (x_1, x_2, .., x_n)^T$ is a vector, which includes results of n measurements made during the in-service inspection. According to Bayes theorem, the posterior distribution $f''_{\theta}(\theta)$ of φ is then

$$f''_{\theta}(\theta) = \frac{L(\theta|x')\, f'_{\theta}(\theta)}{\int_{\theta} L(\theta|x')\, f'_{\theta}(\theta)\ d\theta} \tag{B.2}$$

where

$L(\theta \mid \mathbf{x}')$ is a likelihood function, which is proportional to the conditional probabilities $f_{X|\theta}(x_i|\theta), \quad (i = 1, 2, ..n)$ of making the measurements as

$$L(\theta \mid \mathbf{x}') \propto \prod_{i=1}^{n} f_{X|\theta}(x_i|\theta) \tag{B.3}$$

The following predictive distribution of X is then used to estimate the updated probability of failure.

$$f_X(x) = \int_{\theta} f_{X|\theta}(x \mid \theta)\, f''_{\theta}(\theta)\, d\theta \tag{B.4}$$

Proof load testing can be used to verify the resistance of an existing structure (or its components). The observation that a structure has survived a proof load test indicates only that the minimum resistance of the structure is greater than the applied load effect — it does not reveal the actual resistance of the structure, nor does it provide a meaningful measure of structural safety. However, results of proof load testing can be analysed using a probabilistic (or reliability) approach. If a structure has survived a known proof load then the original cumulative distribution function, $F'_R(r)$, of the structure resistance is simply truncated at this known load effect, QPL, so that the updated distribution function of the resistance, $F_R''(r)$, is given by

$$F_R''(r) = \frac{F_R'(r) - F_R'(Q_{PL})}{1 - F_R'(Q_{PL})} \tag{B.5}$$

Satisfactory structural performance during T years in service means that the structural resistance is greater than the maximum load effect over this period of time. The updated distribution function of structural resistance at time T is then given by

$$F_R''(r) = \frac{\int_0^r F_Q^T(r) f_R'(r) dr}{\int_0^\infty F_Q^T(r) f_R'(r) dr} \tag{B.6}$$

where

F_Q^T is the cumulative distribution of the maximum load effect over T years;

$f_R'(r)$ is the probability density function of the resistance prior to loading.

B.5 Inspection strategy

It is highly desirable that in-service structural inspection strategy be initially developed for a structure during its design based on generic data for similar structures under similar loading and environmental conditions. Information obtained by modelling the effects of potential degradation processes over the design working life of the structure can also be used. It is important to optimize the inspection schedule regarding the life cycle cost of the structure.

The ability of different inspection methods (visual and NDE) to detect damages and defects depends on the nature of the latter. Whenever it is possible to identify possible causes of damage or potential defects, it is also possible to devise appropriate inspection strategies, i.e. where to inspect, with which method, and how often. However, it is also essential to schedule periodic inspections to detect possible unforeseen or simply unknown phenomena which can damage structural integrity. This is especially important at the beginning of the structure life when errors made in design and construction can reveal themselves. In this context, a baseline inspection to determine the initial condition of the structure after the completion of construction is needed. In later stages, such phenomena could be related to damages due to accidents. An unscheduled inspection might be needed after an accident based on the accident report. In such cases, a visual inspection covering the total extent of the structure is usually useful.

The inspection strategy should be periodically updated throughout the service life of a structure, usually through amendments following the receipt of new data, results of the structure assessments, and other data or information relevant to the SIM process. Inspection frequency and extent should be justified by cost-benefit analysis.

Risk-based inspection (RBI) planning can be used to optimize inspection strategy. The methodology takes into account risks associated with failures of components of a structure and usually involves the use of probabilistic models of structural deterioration and inspections, which are combined via Bayesian updating. The optimization is based on minimising the total expected cost over the service life of the structure, which includes the costs of the structure failure, inspections, and repair, while acceptable probabilities of failure serve as constraints.[17]

An inspection by itself obviously does not improve integrity of a structure. Thus, it is essential along with inspection strategy to develop plans for the structure maintenance, repair, and/or replacement, which are informed by inspection outcomes. A comprehensive strategy, which includes inspections, maintenance, and repair actions, can be developed by minimising the life cycle cost of a structure.[3] Figure B.3 illustrates the implementation of SIM over the lifetime of a structure under different scenarios.

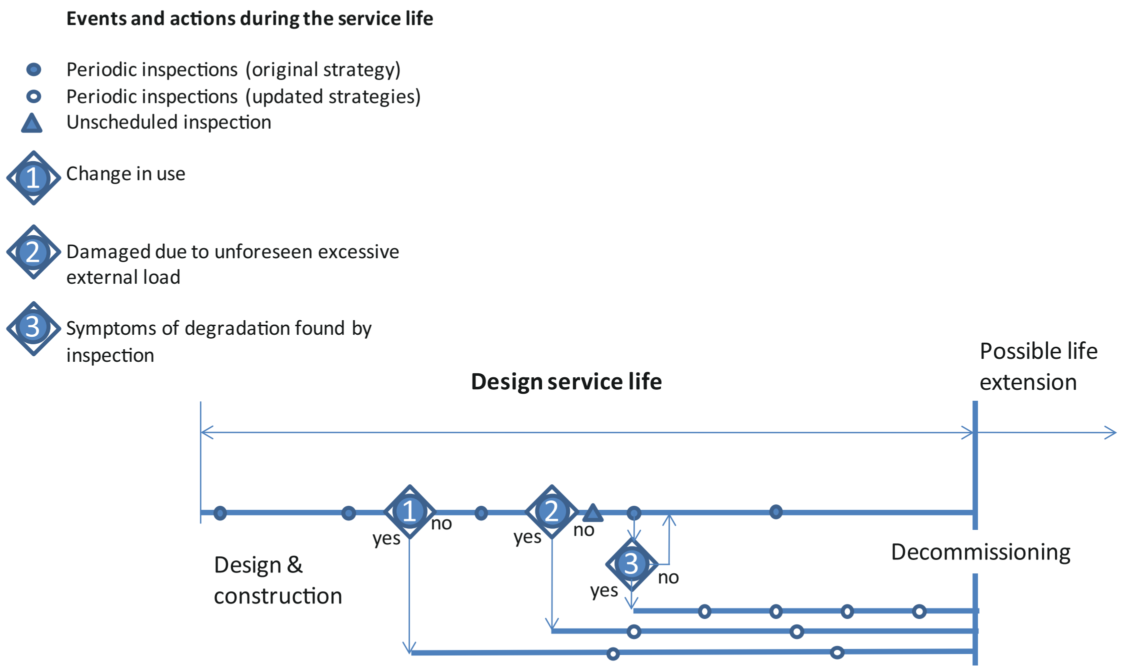

Figure B.3 — Events and actions associated with SIM over the lifetime of a structure

B.6 Inspection programme

The inspection programme is the detailed scope of work developed from the inspection strategy. The programme requires schedules, budgets, personnel profiles, and other procedures, in particular the selection of appropriate inspections methods and procedures, before it can be implemented.