Using a condition-dependent approach to maintenance to control costs and performances

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Abstract

By adopting a condition-depended approach to maintenance, facility managers can exercise control over the desired maintenance performance levels and costs. The practise of condition assessment by building inspectors yielded variable results due to subjective perceptions of inspectors. Nowadays well-trained building inspectors are able to manage condition surveys and provide property managers with objective, reliable information about performance loss and defects of building components. The implementation of various performance levels in planned maintenance requires not only the standardisation of the condition assessment method, but also the related planning methodology. This paper describes findings from research that examined the methodology of condition assessment of building components using a six-point condition scale in the Netherlands. We distinguish different categories of performance loss in maintenance and link that to different kinds of maintenance activities.

Keywords: condition assessment, defect, maintenance, performance, six-point condition scale

Introduction

Asset management and property management should be based on objective, reliable information about the performance of buildings and building components. Data collected during a condition survey on-site is needed for strategic policy making, and for maintenance planning by the maintenance staff. Supplementary information is needed for executing maintenance works. A condition-dependent approach to planned maintenance leads to a decoupling of quality assessment from the determination of maintenance activities. It also provides possibilities for differing performances of building components and maintenance performance levels.

This article is based on the results of several research projects. First we carried out a research project about technical management processes by Dutch housing associations (Straub, 2001). The research questions were how housing associations carry out technical management processes at present and how, in the future, they could carry out the technical management processes in a professional, client-centred and sustainable manner. The design of a model relationship between asset management and technical management by housing associations features prominently in the research project. In this paper we focus on planned maintenance, being a major part of technical management processes of all facility managers. The question how to perform professional: effectively and efficiently, will be answered. Technical management processes, in which a client-centred approach features more prominently involve responsive maintenance, relet maintenance and minor improvement to the interior of dwellings or workplaces (Straub, 2002). Secondly we analysed condition assessment methods applied in the Netherlands by The Government Buildings Agency, The Ministry of Housing, Spatial Planning and Environment, facility managers, consultants and contractors, using standard lists of defects and a six-point condition scale. Some methods just interfere with the collecting of the data, other methods also involve a planning method to set and calculate various maintenance performance levels (Straub, 2002). Almost the same method as used in the Dutch House Condition Survey by the Ministry of Housing has been used in a research project funded by the European Commission Brite Euram programme to improve the art and science in condition-based maintenance systems (Damen Consultants et al, 1996). OTB Research Institute for Housing, Urban and Mobility Studies were one of the co-operating partners in this project.

Performance loss and defects

All building components have to contend with performance loss through ageing, use, and external causes. The relationship between defects and performance loss has been studied by many authors (e.g. Adlleson, 1989; Damen Consultants et al, 1996; Hermans, 1995). Hermans (1995) shows that the relationship between degradation and performance loss can take place according to three patterns (see figure 1):

1. performance loss manifests itself as continuously decreasing while degradation continuously increasing;
2. the performance remains constant while degradation declines continuously; performance loss manifest abruptly;
3. performance loss and degradation act independently;

We think that this distinction is important to describe influences of maintenance activities on performance loss. Besides, it is essential to know turning points in performance loss and degradation and to determine optimal points of time for maintenance actions. Under ideal circumstances it would be possible to have the maintenance of a building completely planned into a series of routine maintenance and replacement cycles (just-in-time). If performance loss and failures have occurred, the facility manager has to carry out corrective maintenance.

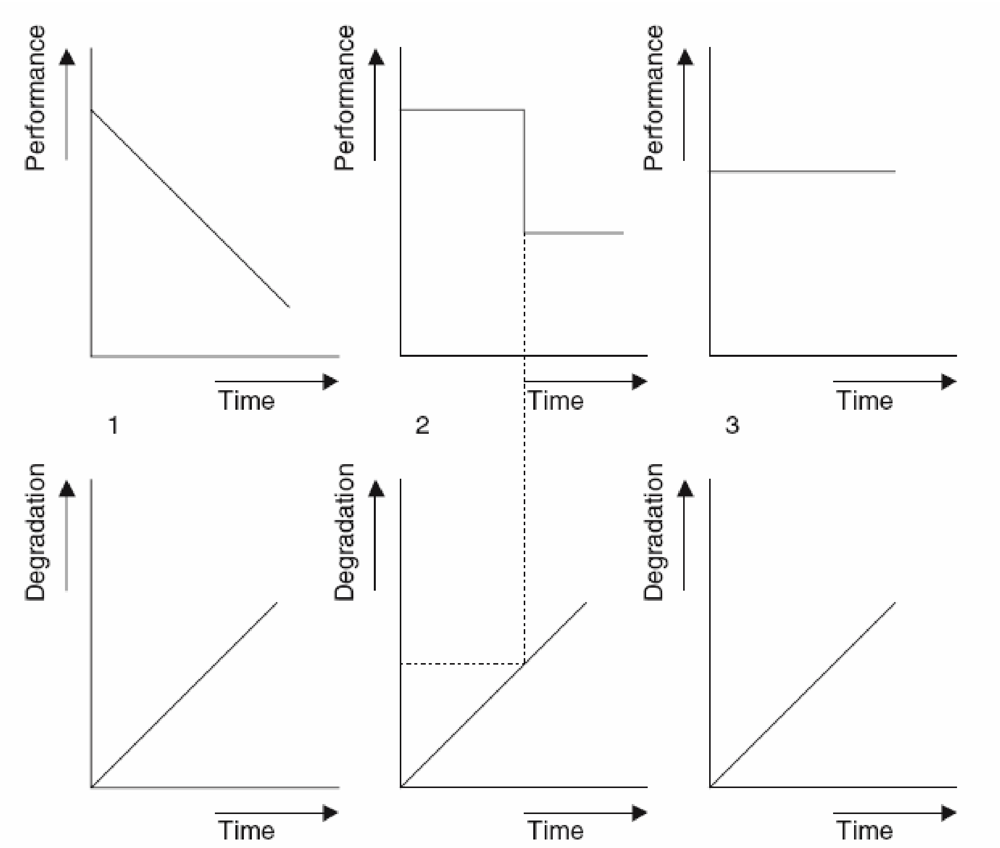

Figure 1: Relationship between performance loss and degradation (Hermans, 1995)

Categories of performance

The above-mentioned studies concerning performance loss and defects are limited in that they observe that performance loss is the opposite of degradation or defects. All defects are of a technical nature. In our research project we distinguish different kinds of performance loss in maintenance and link that to different kinds of maintenance activities (Straub, 2001). The international standard ISO 6241 (ISO, 1984) classifies 14 categories of performance of building components. In reference to this standard, we distinguish between:

- technical performance;
- fire safety;
- utilisation safety;
- social safety;
- health and the interior environment;
- functionality and availability;
- maintainability;
- aesthetic performance;
- energy performance;
- water performance;
- sustainable use of materials.

We apply those performance categories also to maintenance activities. In general, acceptable performance loss and the implementation of appropriate maintenance activities depend on legal requirements, technical and functional motives, and environmental aims. Insufficient funds mean priority setting of maintenance work for the whole stock and building components.

Maintenance activities influence the performance of building components at a particular point in time. We consider replacement of building components and the installation of new building components as maintenance activities. In fact, through functional material modifications and installing new building components, performance alterations take place. The product characteristics of the building change and the original performance capacity increases.

Condition assessment

Performance loss is measured in terms of defects ascertained. The defects are registered during a survey. The practise of condition assessment by building inspectors yielded variable results due to subjective perceptions of inspectors. A lot of research has been done to create objectivity in the inspection process, that should result in unambiguous information for maintenance strategies (e.g. Damen et al, 1996). We agree with Chandler (1995) in that condition assessment should be used as a strategic management tool. A condition survey is a tool in assessing the technical performance of the properties to underpin the long-term maintenance expectations. The information is meant at first for strategic management. Condition assessment is not meant for preparing the year maintenance budget and planning of the work. Supplementary information is needed in the phase of preparing execution of remedial work.

Six-point condition scale

Most respondents of a questionnaire survey of housing associations in 1997 registered defects and the extent of those defects during inspection on-site, and described the condition state using words like good and fair (Straub, 2001). Nowadays condition marks are being used more frequently. A lot of authors point out the need for clearly defined condition categories. Pitt (1997) says that whatever condition categories are adopted, essential is that they are clearly defined. Data collectors are well trained to ensure data consistency and reliability. As a result of several research projects and the use of the method in the Dutch House Condition Survey, the process of condition assessment using standard lists of defects and a six-point scale has become popular by facility managers, consultants and contractors in the Netherlands. The condition categories are of a chronological order that describe possibly occurring defects without references to remedial work. Tables 1 and 2 give examples of general descriptions of condition marks.

Value	**General condition description**
1	New building condition.
2	None or only slight defects. Some visible symptoms of the ageing process.
3	Many slight and /or some substantial defects.
4	Substantial defects. Limited service life left.
5	Very substantial defects. Replacement of major repair is necessary.
6	The component has reached the end of its service life. Replacement of the component is long overdue.

Table 1: Six-point condition scale Brite Euram project (Damen et al, 1996)

Value	Definition	General condition description
1	Excellent	New completion quality, reflecting sound design, workmanship and choice of materials. In incidental cases defects may occur due to calamities (e.g. vandalism) but not to ageing.
2	Good	Influences of use and weather manifest to some degree. The element is broken in; the newness is gone. Functional use is definitely guaranteed.
3	Fair	Influences of use and weather manifest in the first serious defects. The ageing process is clearly underway in nearly all respects. In incidental cases, disturbance may occur in the functional use.
4	Poor	The ageing process has the element firmly in its grip. It is past its prime, the end is nigh. Disruption of the functional use occurs in some places and/or has already occurred more often.
5	Bad	The ageing process is more or less irreversible. Critical defects occur regularly. The functional use of the entity is no longer guaranteed. The end point has actually been reached.
6	Very bad	The ageing process is so advanced that there is continual disruption in functional use of the element.

Table 2: Six-point condition scale Dutch House Condition Survey (MVROM/Damen Consultants, 1994)

The use of a six-point scale is maybe special for the Netherlands. In for instance Norway, Scotland and England a four-point scale is used. The standard used in the English House Condition Survey adopts the categories: seriously defective or unfit, defective, just acceptable and satisfactory (Department of the Environment, 1991). An important observation is the scale division. The six-point condition scale is not linear but ordinal. An ordinal scale division means that the values the variable can have can be classified, but their meaning is not univocal. A building component in condition 3 does not mean 3 times being worse than a component in condition 1. Condition 1 indicates the upper value of the scale. This absolute value can not be exceeded. Condition 5 indicates the lower value of the scale. This bad condition is not an absolute value. Condition 6 has been added to distinguish a very bad situation, meaning that the component should already have been replaced. A linear scale division presupposes a linear relationship between the conditions and the remaining life span (service life) of the building components (see figure 2). In reality performance loss and life span of discrete building components and sets will run differently. Figure 3 shows the relation between performance loss through ageing of building components and condition marks. Figure 4 shows what happens if calamities, e.g. broken windows, take place.

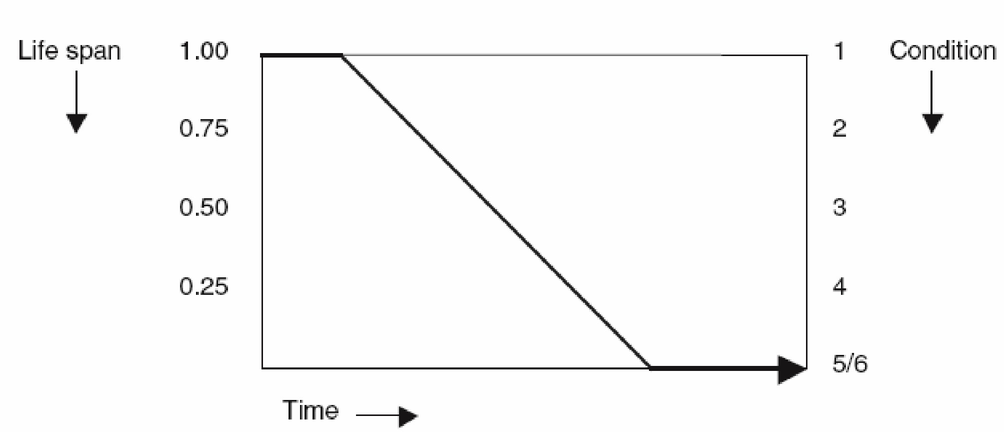

Figure 2: Six-point condition scale and remaining life span

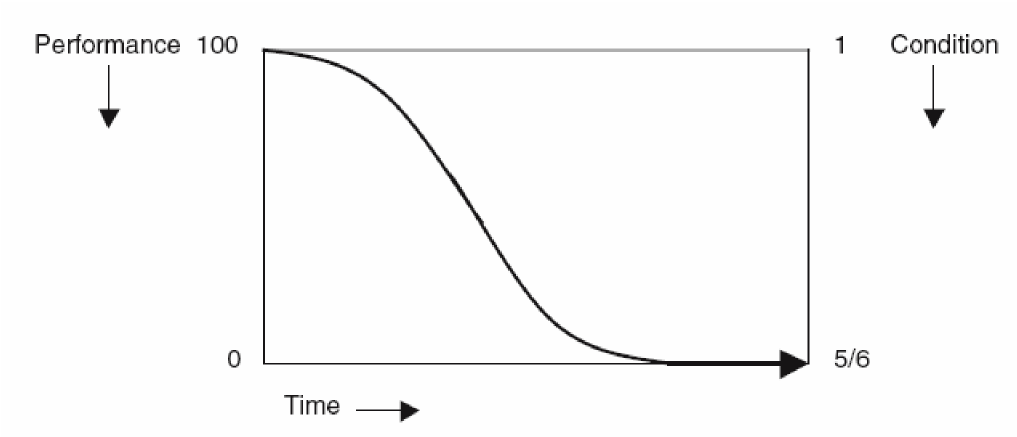

Figure 3: Six-point condition scale: performance loss through ageing

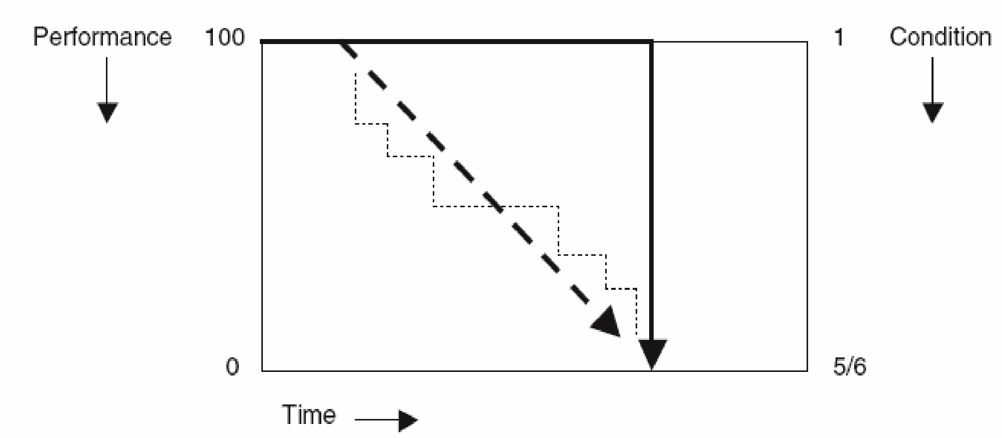

Figure 4: Six-point condition scale: performance loss calamities

Condition assessment methods

There is not just one condition assessment method. Facility managers and consultants have developed their own method based upon comparable starting-points. The methods vary for the hierarchical classification of building components, classified defects and the use of condition parameters. All condition assessment methods follow the same pattern. See figure 5. The assessing of defects occurs first. Without this information one could not formulate maintenance activities and estimate costs. A visual inspection will usually suffice. Subsequently the inspector passes through the following condition parameters:

- type of defects;
- intensity of defects;
- extent of defects.

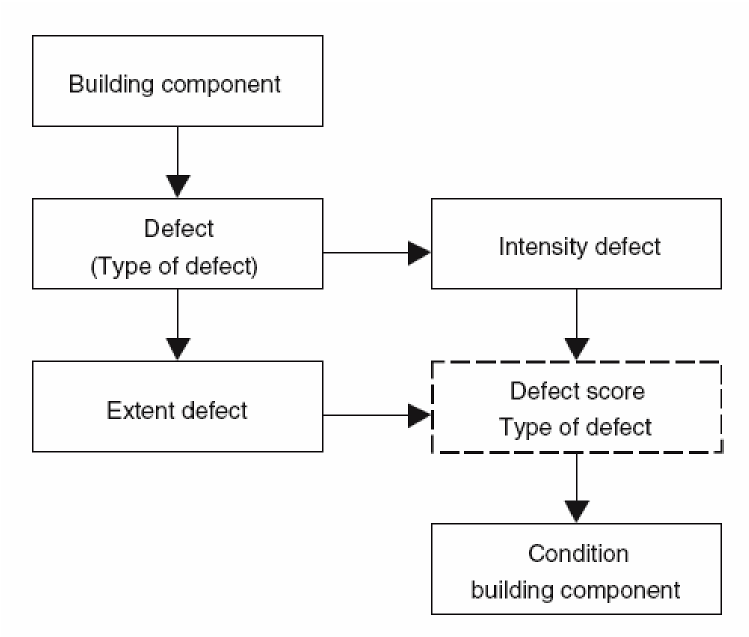

Figure 5: Condition assessment process

Type of defects

The type or seriousness of the defect indicates to what extent it influences the functioning of building components. Most condition assessment methods classify the type of defects of distinct building components with minor, serious and critical. Critical defects significantly threaten the function of the building component. Generally material intrinsic defects like corrosion and dry rot, defects that threaten the building structure, e.g. stability and distortion, and 'functional defects', are weighted as critical defects. Functional defects are those that are already associated with a breakdown in performance: symptoms. The impact of a defect – which also may occur to another building component –, for example leaking, is registered. Serious defects are gradually damaging the performance of building components, for example defects in the material surface. Defects to secondary components, for example finishing coats, are classified as minor defects. Usually those defects do not effect the primary function of building components. However, classifying all defects of finishing coats as minor defects, could be inaccurate. Applied to building components, defects to finishing coats can be treated in the same manner as other building components. That means that a separate defect list should be formulated for paint films. According to this list, critical defects are for instance blistering and detaching of paint films. Reducing of gloss can be classified as a minor defect. Nevertheless, the substratum of the paint should be clear. Building component classifications often lack a distinct relationship between substrates and finishing coats. It is clear that the classification of defects is a compromise of theoretical knowledge, a methodically approach and pragmatically reasons. Not meeting with current building regulations is classified in some methods as a critical defect. This indicates just the reason why one should apply a maintenance activity, but does not describe the actual technical state.

Intensity of defects

The intensity of defects strongly influences the condition of building components. The intensity of defects deals with the degradation process. Some methods name this the depth of the defect or the visible distance. The methods used in the Netherlands are in two or three intensity classes. We consider that well-trained building inspectors are capable of easily assessing the intensity of a defect. Pictures can be helpful as a reference. Theoretically, one could question the need to indicate intensities for all occurring defects. This comment deals with the cause of defects. Ageing defects like material intrinsic defects and defects involving the material surface, e.g. wear and soiling, develop over a certain period and will occur in several intensities. But defects caused by calamities, for instance glass breakage, just occur in one stage. Other methodological problems form so-called functional defects, e.g. the already mentioned leaking. In this case one or more technical defects have been developed a long way off. The leakage is the end result. Once again the pragmatism is more important than the theoretical methodological correctness, as long as the method remains objective and leads to useful information. For example one may register the frequency of defects in stead of intensity. The frequency of failures is particularly a useful condition parameter for condition assessment in the case of building services components.

Extent of defects

Besides knowledge about the intensity of defects knowledge about the extent of defects is needed to assess the condition. The condition assessment methods use three, four or five classes for the extent of defects, for example < 2%, 2-10%, 10-30%, 30-60% and > 60%. Some methods relate turning points to the particular building component and the type of defects assessed. For example a painting research and consulting firm classifies the extent of surface deposit (pollution) into < 10%, 10-50% and > 50 and classifies cracking of the substrate into < 1%, 1 to 5% and >5% (COT, 1998). For assessing some of the defects COT refers to official international standards, e.g. ISO 4628 Paint and varnishes. Methodological questions rise how many classes be manageable for building inspectors and how many classes be useful to link maintenance activities to the extent of defects in the policy making process. Clearly, to estimate the extent and chose for the appropriate class is difficult, even for more experienced building inspectors. Especially during the starting phase of a new introduced condition assessment method surveyor variability is considerable. The inspector has to estimate the damaged part of the component in comparison to the whole of the considered component, while taking a random check. Obviously difficulties doing so also depend on the defect involved. One may differentiate general ageing defects normally covering the whole building component from localised defects. In the case of general ageing defects the intensity of a defect corresponds with the condition.

Defect scores and condition marks

The extent and the intensity of a defect combined with the type of the defect lead to a condition mark, probably with a defect score as an intermediary product. It is notable that several condition assessment methods lead to variable resulting condition marks, whilst examining the same defects. We give as example paintwork applied to wooden window frames flaking off. The building inspector assesses the intensity as advanced and estimates the extent at 25%. Dependent on the method the condition mark will be between 4 and 5. If the surveyor estimates the extent for 33%, the condition mark varies between 4 and 6. The different results of various methods are not a drawback in practice. Important is that within an organisation all building inspectors handle they're own method the same way. However, it could be a handicap in the transfer of people and knowledge between facility managers, consultants and maintenance contractors. A first step to standardise the condition assessment methodology has been made in 2002 by the Dutch Standardisation Institute. A Dutch standardisation commission will work on the standardisation of condition parameters, scales and a hierarchical classification of building components.

Example Brite Euram project (Damen Consultants et al, 1996)
The Brite Euram project contains standard lists of defects for over 100 elements and instructions how to measure the condition parameters. In the Brite Euram project condition assessment is based upon functional, technical and aesthetic criteria, and the basis quality of the element. Those criteria have been related to most common defects, which may affect the element. The defects are classified in minor, serious and critical defects. The criteria used for assessment under the heading basic quality are the initial reaction to the state of the element, e.g. the significance of the position of a defect and the colour of the element. Consideration is also be given to how the element compares to the same as new (the initial performance): design, used material, workmanship and previous maintenance operations.
Considering the example of wood window frames and paints to woodwork principal functional requirements relates to the partition between internal and external spaces (acoustical, safety, climatic and visual), the natural lighting and the natural ventilation properties. Opening lights and doors should open and shut. The main functional criteria that wood windows must satisfy are resistance to air and water, condensation control, no fire propagation, levelness of surfaces and absence of roughness, reparability, non-emission of odours and thermal and acoustic insulation. These criteria involve the structural frame, the type of wood use, the techniques used in assembling and finishing the elements, the gaskets and sealing system. Functional defects include:

- moisture retention;
- degradation of gaskets;
- ageing of sealants;
- deterioration of protective layer.

The main technical criteria that wood windows should satisfy are stability, reliability, wind resistance, resistance to impact and resistance to solar radiation. These criteria involve the fixes and mobile frames of the window. Because of the distortion and leaking of elements, for example, the window can not properly shut and secured with the consequent worsening of its technical performance (as well as its functional and aesthetic performance). Technical defects include:

- fissures;
- fungal infection;
- insect attack;
- rot;
- joints opening;
- distortion and leaking.

The main aesthetic criteria that wood windows should satisfy are absence of surface defects, homogeneity of colour and finishes and homogeneity of the ageing process. These criteria involve the surface and finish of the window. Aesthetic defects include:

- surface deposit;
- discoloration;
- deterioration of surface finishes.

The classification of defects has been based on the threat to the function of the windows caused by the type of defect. See table 3.

Critical defects	Serious defects	Minor defects
Distortion and leaking	Ageing of sealants	Deterioration of surface finishes
Fissures and breakage of frame	Degradation of gaskets	Discoloration
Fungal infection	Loss of protective layer	Glass surface discoloration
Glass cracking	Misting of double glazed units	Surface deposit
Insect attack	Moisture retention	
Missing of parts		

Table 3: Classifying defects wood windows and window frames (Damen Consultants et al, 1996)

All defects with a certain extent and intensity are related to condition marks. That makes the condition assessment method applied in the Brite Euram project very complicated. See table 4.

Type of defect	**Extent**		**Intensity**	
Critical	**Sporadic**	**Starting**	**Obvious**	**Advanced**
Distortion and leaking	< 15%	Scarcely visible **3**	Clearly visible **4**	Frames don't fit together **5**
Fissures and breakage of frame	< 15%	Not applicable **5**	-	-
Fungal infection	< 15%	Stains and mould **4**	Mould and holes **5**	Dry/wet rot **6**
Glass cracking	< 15%	Not applicable **6**	-	-
Insect attack	< 15%	Pinholes/flight holes **4**	Brittle/friable **5**	Hollowness **6**
Missing of parts	< 15%	Not applicable **6**	-	-

Table 4: Condition marks sporadic critical defects related to intensity of defects of wood windows and window frames (Damen Consultants et al, 1996)

Restrictions to the condition assessment methods

Condition assessment would be a simple, uniform measurement method for building performance. Results are unambiguous and verifiable. This improves the communication between inspectors, the responsible maintenance planning department and management. The analysed condition surveys involve a lot of steps, procedures and paperwork. They introduce condition marks, defect scores, condition parameters, etc. The example from the Brite Euram project shows how complicated it may work. Because of this it means a clear break of the common working processes of building inspectors. Facility managers will doubt the benefits of a new method and especially the willingness and skills of their inspectors to work in that way. Experience shows that well-trained inspectors are able to manage condition surveys. The most difficult part is to forget about the old way of thinking and working. Building inspectors have enough knowledge and experience about elements, defects and remedial work. However, it takes a lot of effort and time to use it in a different way: register the found situation and separately choose for maintenance activities. Inspectors need standard lists of defects. Agreements about measuring the extent and the intensity of defects should be very clear. If inspectors are made responsible for the choice of maintenance activities based on condition data, they also need good instructions how to do that including a standard list of activities. Depending on the used condition assessment method a maintenance-planning department will choose those activities at the office.

Another drawback for using a condition assessment method is the amount of data to be gathered. Although a computer will be used for processing the data, there are reasons to limit

gathering of the data. To make the best of the condition survey, the data must be continuously updated. Failure to maintain accurate information on the databases will lead to additional costs for reassessing quantitative and qualitative information of elements. Furthermore inaccurate information will undermine the credibility of subsequent management decisions (Chandler 1995). Limitations of the data gathering could be found in the variety of building components to assess, in making appropriate random checks and in the division of building components into elements and sub-elements. A limited number of building components, e.g. painting work, woodwork in facades, flat roofs and building services, determine the larger part of the maintenance cost. Condition assessment could be limited to those components.
For an objective visual assessment building inspectors need a clearly defined and hierarchical classification of building components. This hierarchical classification directly influences the classification of the type of defects. It should be related to possible maintenance activities: maintenance cost elements. For instance on the level of flat roof finishes, e.g. bituminous roll, or roof drainage (gutters and drainpipes) one could assess defects with a certain extent and intensity. Building inspectors are not able to assess defects on a higher hierarchical level, like flat roofs including all finishes and secondary components.

Implementation of maintenance performance levels

Formulating maintenance performance levels in planned maintenance mean deliberate about maximum performance loss, appropriate maintenance activities and the available financial means. It should be possible to calculate several alternatives and to set priorities to certain maintenance activities. We think condition based building maintenance using the six-point scale as a yardstick gives a useful tool for inspection and planning maintenance work. Facility managers are able to set maintenance performance levels by forecasting the condition state of components after executing maintenance activities, dealing with more and less acceptable remaining defects. See figure 6.

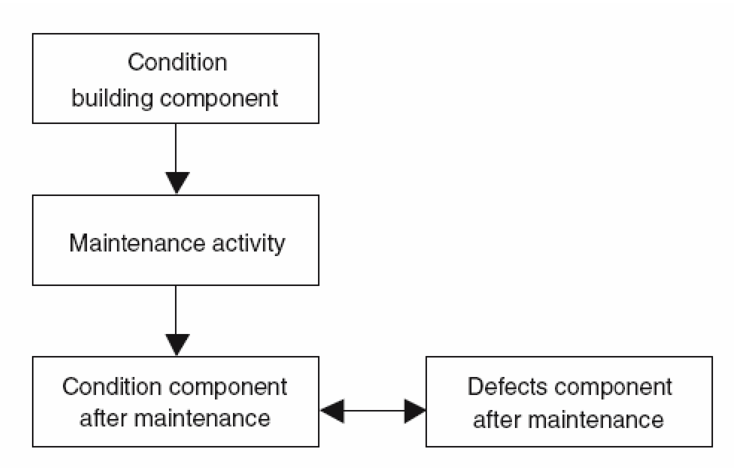

Figure 6: Condition assessment process after execution maintenance work

Maintenance activities

Maintenance activities can be distinguished according to type (repair, replacement, (re)painting and cleaning), part of the building component to which an activity applies, the specification of materials, the quantity of the work, the frequency of short cyclical preventive maintenance actions and the nature of an activity (preventive or corrective). To perform efficiently and effectively the condition – the performance – of a building component after executing maintenance work should be clear. We found that the condition of building components after partial replacements, repairs and cleaning is not clear for most facility managers (Straub, 2001).

After an integral replacement of the component the condition will be as new. In case of partial replacements and repairs the condition gap before and after the activity is insecure. That depends on the solved defects at that particular moment of time. Hermans (1995) found that cleaning and repainting of surfaces does not influence the technical performance of substrates. The degradation will just process more gradually. Nevertheless, the aesthetic performance of a surface improves.

Performance standards planned maintenance

Just as the collection of survey data the decision-making process for planned maintenance holds subjective elements and often is not transparent. Advanced maintenance management systems enable users to calculate maintenance performance levels based on the condition of building components after executing maintenance work. In this approach assessed defects and condition marks before at one side and acceptable defects and conditions marks after executing maintenance work at the other side, are steering instruments in the planning process. Doing so, one has to examine the consequences of the proposed maintenance work for the assessed condition and to answer questions like: What is the new performance of the building component compared to the initial performance and which defects have been solved and which defects are still present?

Planning methods linked to condition assessment methods work with different principles for standardisation of condition marks. An example is to set a lower limit in the condition scale. See figure 7. Such a method enables facility managers to vary performance levels in planned maintenance, for example very low, low, standard and high. To distinguish between performances of building components, e.g. the technical performance, aesthetic performance and sustainability performances (energy, water, sustainable use of materials), and to formulate service level agreements per building component, requires very advanced planning methods. One should have the opportunity to adapt the weights of defects afterwards, in the phase of formulating long-term maintenance plans. We can explain that with an example. As a reference point for building inspectors mechanical damages to window frames are weighted normally as serious defects. However for aesthetic reasons, the property manager can weight the defect as a critical defect. Doing that the condition mark rises and probably will exceed a condition standard.

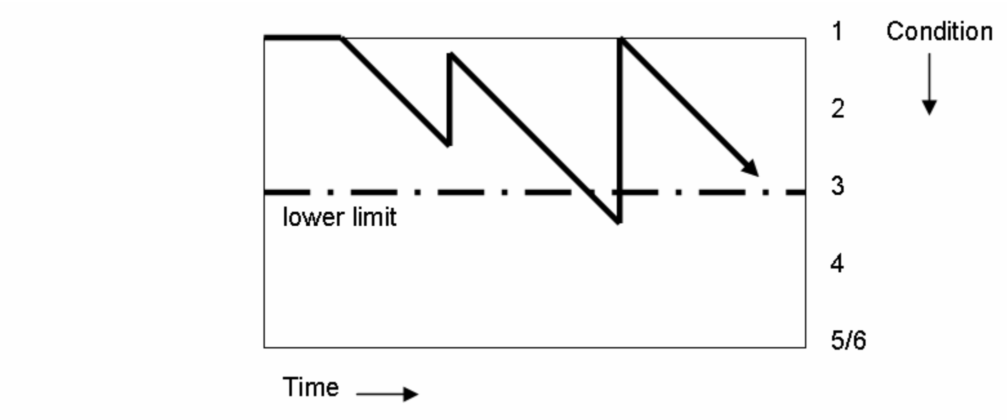

Figure 7: Six-point scale: condition standard

Maintenance management systems

We found that most maintenance management systems are lacking possibilities to calculate maintenance performance levels in planned maintenance. The systems just support the tuning of the ‘maintenance stock’ for the available budget by setting priorities. Normally, maintenance work needed to secure the safety performances has precedence to work just for aesthetic or sustainable reasons. The initial year of the latter work will be delayed. Shen and Spedding describe a multi-attribute model for priority setting in planned maintenance (Shen and Spedding 1998). We think that the assessment and setting of priorities for planned maintenance work is a way to tackle problems of lacking maintenance funds. In addition to this using the condition scale in the planning process gives the opportunity to vary the performances of building components.

Conclusions

Condition-based building maintenance using the six-point scale as a yardstick gives a useful tool for inspection and planning maintenance work. Building inspectors can provide facility managers with objective data about performance loss and defects of building components. Facility managers have to formulate guidelines with standard lists of defects and agreements about measuring the extent and the intensity of defects. Drawbacks of condition assessment methods are the amount of data, data that must be updated continuously. We think once in three years. Facility managers should bear in mind that condition assessment is not meant for preparing the year maintenance budget and planning of the work. A limited number of building components determines the larger part of the maintenance cost. Condition assessment could be limited to those components. Supplementary information is needed in the phase of preparing execution of remedial work.

The facility managers are able to set maintenance performance levels by forecasting the condition state of components after executing maintenance activities, dealing with more and less acceptable remaining defects. Assessment and setting of priorities for planned maintenance work is a way to tackle problems of lacking maintenance funds. Varying performance levels is just advisable in the case of a diverse portfolio and if the maintenance management system easily provides possibilities to do so. Maintenance management systems should also link the performance levels en especially the costs to the asset management of the organisation.

In the Netherlands performance-based service contracts are at the centre of attention of facility managers and maintenance contractors, especially for planned painting work, woodwork in facades and flat roofs. The application of performance-based maintenance contracts implies a condition-dependent approach to maintenance. Such an approach provides facility managers with opportunities to influence costs, financial risks and quality of the properties in the long-term. Even in the case that the execution of maintenance work, preceding steps to specify maintenance work and the condition assessment are contracted out, facility managers need knowledge about condition assessment and performance. For example whilst a traditional maintenance contract can be based upon the maximum required performance of building components, a performance-based maintenance contract should be based upon the minimal performance of building components.

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