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# Plant maintenance in hospitals facilities

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**Abstract.** Maintenance is crucial in hospitals, where potential systems failures can have a significant impact on patients. An hospital is a complex asset because of the co-existence of multiple areas and interaction among health-related and non-health-related activities. The central hypothesis is that the appropriate maintenance procedure depends on served spaces and plants. Therefore, the research aims at establishing a correlation between the operational criticalities of each area and critical elements of plants to improve and optimize the execution of maintenance activities. The analysis is based on three steps. Firstly, the identification of criteria aimed at defining the plants criticality in correlation with the ways in which spaces are served and, moreover, definition of criteria for spaces classification based on performed activities. Last step is the description of components through two categories of factors. The first refers to analysis of design and functioning aspects of plants; the second is related to components functioning and deterioration. This correlation among “criticality index” and “health index” for all components provides indications on modalities and priorities for extraordinary interventions. Relative weights were attributed through the consultation with hospital technical office. The proposed maintenance management was applied in a hospital made up of 65000 squared-meters to include it in the informatic system that is currently used for repairs. This new maintenance management has the purpose of providing indications for maintenance strategies by considering contemporary nature of functional spaces, activities design characteristics and health state of them. The implementation into the informatic system and its check will be developed in future.

## 1. Introduction

The demand of healthcare services and facilities is increasing in last years because of growing life expectancy, elevated standard life and scientific progresses [1]. The result is the realization of large urban hospitals capable of providing a set of healthcare services to patients in a congested and concentrated space.

An hospital works 24 hours a day, 7 days a week, therefore activity continuity and asset availability must be always ensured. This becomes more important in the light of hospital mission: assistance, cure and protection of patients.

Consequently, maintenance has a central role in order to provide to patients the expected service by guaranteeing quality, safety and best technical and economical practices [2].

In such a complex structure, maintenance is carried out on medical devices, mechanical and electrical plants to ensure their functioning, but also on building components such as walls, structures, etc. in order to ensure indoor quality, cleaning and minimal required indoor conditions for the execution of health-related activities [3]. Therefore, maintenance management coordinates these multiple activities by, contemporary, reducing related costs [4].



Usually maintenance is planned based on shared knowledge: it enhances the efficiency of subsystems, extends their useful life, contains costs and relative consumption [5].

Nowadays, indications and suggestions about maintenance management of medical devices are many since they are becoming more and more specialized, various and complex [6]. Nevertheless, a restricted number of indications are given about the asset management and systems maintenance of such structures [7].

Even if the direct potential impact on patients' health is more limited, they contribute to the creation of essential indoor conditions, that are specific and crucial for some areas of interest [8].

Therefore, the purpose of the research is the identification of a new approach to maintenance to improve activities and choose the most appropriate policy for all installed systems by attributing a different level of importance to each component.

This analysis is complicated by the multiplicity of plants in hospitals: some of them are also present in residential buildings while, others are peculiar of healthcare facilities as, in example, nurse call system, medical gases system. As a consequence, this aspect cannot be ignored in the choice of maintenance activities and strategies to be adopted.

Although a minimum maintenance is always carried out, its optimization is achieved by assigning scores and priorities to systems based on their functioning and role. Indeed, functional spaces analysis influences maintenance activities too [9]. The adopted methodology was firstly focused on analysis of functional spaces in term of needs, their spatial distribution and interrelation among them, nature of performed activities and existing criticalities. Similarly, systems examination was oriented towards the definition of the functioning principle, a fault chain identification to ensure their service continuity and definition of critical issues to have a relative classification of them. These two categories are then related by using a matrix of relation for a general use and, for the specific application, into a combination of factors able to give an immediate perception of plant state by focusing attention on their design characteristics, ageing and degradation.

## **2. State of the art (on healthcare maintenance)**

Even if the maintenance management of systems is not a core business of such structures, it has a central and essential role. It guarantees the continuity and functioning of the organization through the realization of needed indoor conditions for the execution of health-related activities [10]. In addition, its purpose is the enhancement of safety, referred to as the limitation of both, probability and severity that a failure can harm a patient and preservation of functionality and dependability of systems subcomponents. It has a significant impact from the economic point of view in the management of such facilities.

Maintenance master plan is usually the adopted document in healthcare facilities to manage maintenance. It includes and details maintenance tasks and relative frequencies, that must be carried out on each system, needed human resources and their skills (the document specifies who must perform each maintenance task), management of available budget and use of KPI to monitor the quality of maintenance.

Corrective maintenance (CM), preventive (or planned) maintenance and predictive maintenance are main adopted strategies [11].

Corrective maintenance occurs whenever a component has a failure or performances are decreasing, thus interventions are in the form of repairs or replacements. Conversely, planned maintenance comprehends periodical repairs or replacements at predefined time intervals. Thus, it is usually the most preferred strategy because it respects manufacturers and regulations prescriptions. The proactive maintenance is based on monitoring of symptoms and likelihood of a failure in order to make in advance interventions based on these measures.

Equally challenging is the definition of extraordinary maintenance, whose purpose is the limitation of degradation and obsolescence. Thus, it includes maintenance activities carried out to refurbish and replace parts or components, also structural, that cause an increase of the book value of the building.

The planning of maintenance activities is partially a consequence of cost and benefit analysis carried out by insurances institutions. However, insurances coverages are guaranteed only if specific conditions are respected. These are typically fixed during the design stage and are associate to the presence of

certifications about chosen materials and components, conditions of installation, availability of maintenance plans, and statements ensuring the compliance with them.

Frequently policies conditions are fixed by consulting manuals that detail maintenance tasks to be carried out during the life cycle of an element.

Nevertheless, some common practices exist. More attention is given to technological stations (thermal stations, cooling stations, generating stations etc.) because the entire building depends on them and to the so-called uninterruptible source of energy and power (UPS and power generator). Technological stations are usually subject to preventive maintenance or planned maintenance in compliance with prescriptions; in case of UPS and power generators, maintenance is carried out based on conditions.

Different is the approach for terminal items, that are directly employed by users. Indeed, in case of their absence in service provision, damages are limited. In case of terminals for which prescriptions exists, planned maintenance is adopted; otherwise corrective maintenance is preferred to limit costs.

The coexistence of highly specialized medical systems and other more common influences the decision to outsource or in-house maintenance. Indeed, medical gases systems, cryogenic systems and technical gases systems need skilled labor. Therefore, maintenance usually is outsourced with a constant presence of maintenance workers, that allow a reduction of work load on internal staff, access to external state of the art and cost efficiency gains. Internal staff usually is involved by monitoring the execution of maintenance activities and their quality [12].

### **3. Methodological approach**

Maintenance of a subsystem is a consequence of its function, role and behavior over time (degradation and ageing). Nevertheless, it can be influenced by the functional space it serves and the system it belongs to. Consequently, to include this priority in maintenance plan, a classification of functional spaces is needed based on criteria able to include all existing critical issues. Indeed, the functional spaces analysis become more significant whenever it considers the nature of carried out activities in terms of needed indoor conditions and required systems. Equally, components' importance is linked to the system they belong to: to have an immediate perception of the relative importance of them, a classification is needed based on existing critical issues.

After the definition of systems and functional spaces classification, their correlation was defined by using a matrix of relation among them. It is essential to improve maintenance because an emergency system has priority in execution of maintenance activities because of the nature of the service it provides otherwise, HVAC system has priority only when it serves an area in which specific indoor conditions are required to respect hygiene conditions.

#### *3.1. Analysis of systems*

The importance of a system is influenced by its function for the execution of a specific activity. Because of this consideration, a classification of them is required to establish their relative order. To do that, criteria were identified.

A ranking of spaces can be realized according to criteria that reflect existing critical issues. Their precise definition is a consequence of dialogue with operative department and health department of healthcare facilities under analysis.

However, economic, operative and health issues always exist but the right importance and relative weights is defined based on managerial decisions and adopted approach by the organization. This depends on chosen strategies in defining criticalities, starting conditions, needs.

However, general systems categories exist and are following:

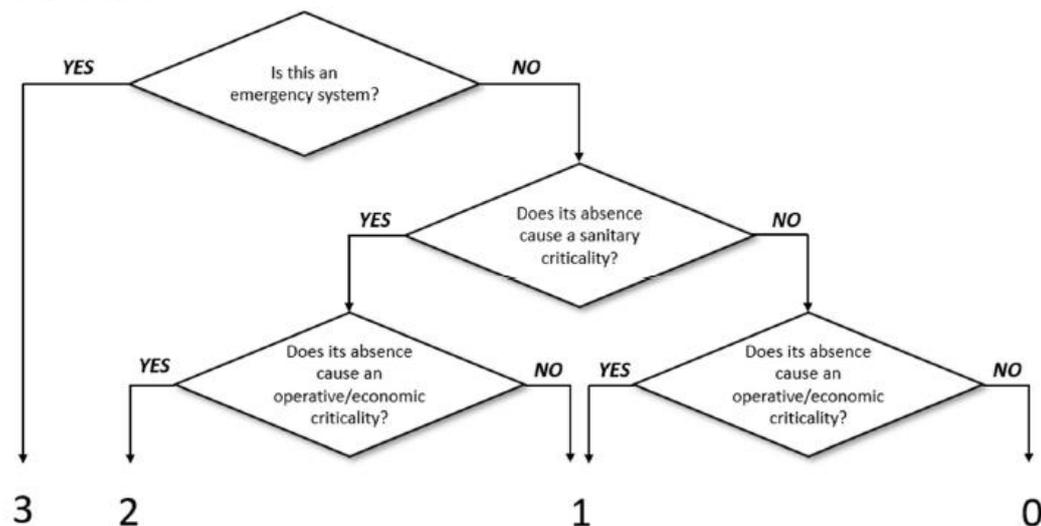
- Emergency systems have priority in maintenance activities execution irrespective of their location because they are required to manage different emergency situations (in case of fire, evacuation, etc.). Maintenance will ensure their functioning in case of need. This category in healthcare facilities includes also systems, whose absence can have a direct potential impact on patient health.
- Systems with sanitary criticalities are those that are required to maintain indoor conditions (in example, temperature, sterility, ventilation, humidity) within a functional space in order to allow

the execution of a specific activity. This group does not include systems that are directly involved in the patients' health.

- Systems characterized by an economic and operative criticality are those that, in case of their absence, cause economic and operative losses. For example, the CCHP systems are introduced to produce energy by exploiting the production of excessive heat and cold. This plant is significant within such a structure in order to reduce the energy use according to the recent European principle of sustainable hospital. Thus, the absence of its functioning is not perceived by patients, personnel but has significant economic impact for the hospital. Definition of operative criticalities is more intuitive: it contains all systems; whose service suspension causes a discomfort or damages the normal operativity of the structure of interest. In example, the suspension of nurse call system does not block the normal execution of activities in the structure but complicates them.

Once criteria for classification are identified and defined, they are organized in a flow chart that guides plants assessment by avoiding every potential influence of subjectivity. In this manner, systems classification is obtained by increasing the score based on attributed criticalities to each system and, consequently, suggests the priority of substitution: the higher is the number of critical issues they have, the higher the priority is.

The following is an example of flow chart: by answering different questions in successions, we have a final differentiation into different groups. The first question is about emergency systems because other criticalities are useless.



**Figure 1.** Flow chart for systems classification: answering questions in succession, their classification is obtained. This base flow can be implemented based on organization needs

### 3.2. Functional spaces analysis

The co-existence of health-related spaces and non-health-related spaces complicates maintenance management but also specifies the need of service continuity in some areas. Health-related functional spaces in healthcare facilities are organized according to the intensity of treatment principle.

This principle is based on possible levels of cure that each patient needs. Three levels are possible: intensive care level includes intensive and sub-intensive therapy units; high care level consists of the high-grade and short-term hospital stay; low care level is devoted to care of post-injuries.

Therefore, an analysis of functional spaces can be a useful support for maintenance activities prioritization. The approach to areas classification is the same of previous analysis.

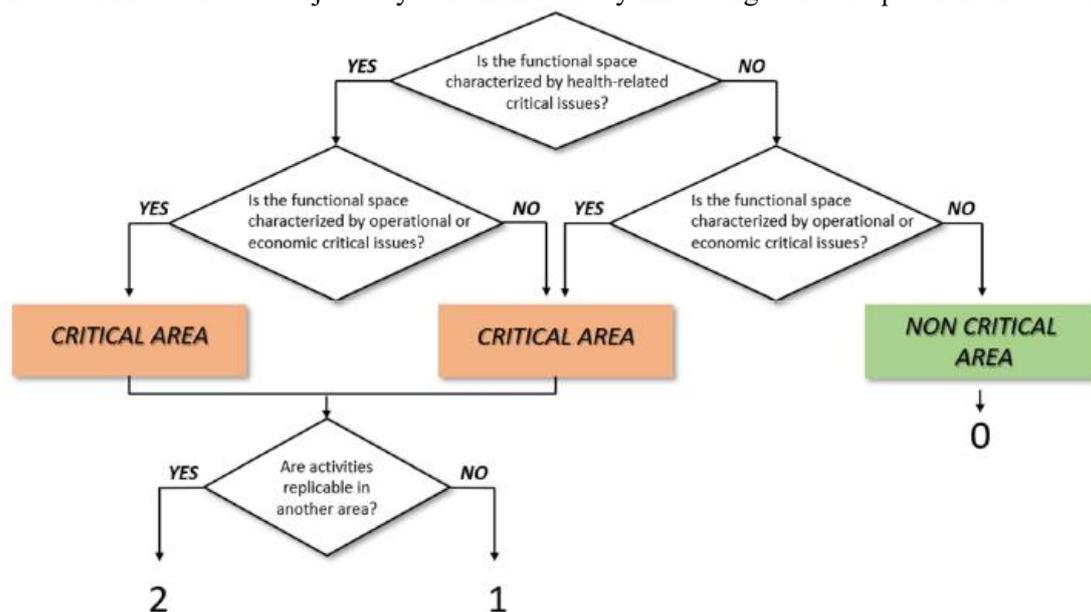
Since a detailed analysis of the entire asset is not possible, aggregated functional spaces were considered. A functional space is a group made up of areas having same or, at least similar, indoor requirements and in which same or, at least similar activities are performed, so that they can be managed together. This clustering is advantageous because it supports an analysis of spaces irrespective of their physical location and, in case of their reorganization, provides immediate indications about criticalities

or needs. General guide lines exist but each organization can re-define them in order to include their own needs and decisions.

Potential existing criticalities in functional spaces are:

- Health-related critical issues are present in those functional spaces that have precise requirements of different nature (such as indoor conditions or availability of medical devices or electrical protection). They are indeed required to allow the execution of any type of health-related activities.
- Operational and economic critical issues are those in functional spaces with health-related and non-health related activities of economic importance. So, any interruption of their execution causes a consistent economic damage. In alternative, it gathers all areas in which health-related and non-health related activities are bonded to the existence of conditions, systems and procedures, so that the absence of at least one of them compromises the normal functioning of the hospital.
- Replicability of activities carried out within a functional space. It is intended as the possibility of an activity to be carried out even in different space than those intended for it. Indeed, systems installed in functional spaces devoted to non-replicable activities requires more control than others. ER activities and procedures can be carried out also in other wards. On the contrary, dialysis is not replicable since it is bound by water treatment plant.

As in the previous classification, criteria can be organized in a flow chart in order to have a classification in absence of subjectivity contamination: by answering different questions in successions,



**Figure 2.** Flow chart for functional spaces classification: answering in sequence, it provides classification of functional spaces. This base flow can be implemented based on organization needs.

we have a final differentiation into different groups. The higher is the number of critical issues the higher the number of categories is.

### 3.3. Matrix of relation

After the classification of functional spaces and systems, the relative relation among them is required because the priority of a system can be increased by the functional space it supplies or, vice versa, if it is installed in an area without specific needs, the priority will remain the same. Therefore, this relation can be represented by a matrix of relation that permits to highlight which are needed systems in every functional area based on nature of performed activities.

	SYSTEMS	Normal electrical system	Emergency electrical system (generators)	Emergency electrical system (UPS)	Emergency lighting system	Fire detection system	HVAC system	Nurse call system	Medical gases system	Anaesthetic gases scavenging disposal system	System for pressure	Medical gases exhaust alarm system	Technical gases system	Discharge system for special wastes	Sanitary system
FUNCTIONAL SPACES															
Outpatients clinics															
Laboratories															
Diagnostic imaging															
Medical and surgery ward															
Operating room															
Delivery room															
Intensive care unit															
Nuclear Medicine															
Radioteraphy unit															
Day Hospital															
Day Surgery															
Pharmacy															
Sterilization unit															
Disinfestation centre															
Mortuary															

**Figure 3.** Matrix of relation showing minimum relation among functional spaces and systems.

This tool has many potentialities because it can express different level of the analysis: the first level corresponds to an initial consultation of main regulations in order to represent indications about minimum requirements for each functional space. Moreover, this matrix can be implemented and adapted to inputs coming from the healthcare facility or hospital its self: in case of an organization interested in the monitoring of CCHP systems, the matrix will attribute more importance to that plant.

### 3.4. Components analysis

Irrespective of previous classifications, maintenance is carried out on individual subsystems.

The order of priority depends also on functional spaces they serve and systems they belong to, but also on their own characteristics: the functioning of the part itself, the surrounding context, potential influences the item can be subject to, their role in the distribution and their degradation.

This maintenance management suggests to attribute two indexes, “criticality index” and “health index” to all systems components. They are combined in a final score that gives indications on modalities and priorities of intervention in case of replacement of items by contemporary including previous classifications.

**3.4.1. Criticality index-IC.** The criticality index - IC expresses importance of maintenance for an item based on design characteristics and its function. As a consequence, an element inherits the criticality of the system it belongs to, according to the previously defined method.

The location of the subsystem along the provision is another aspect to be included: that can be simplified through the following chart.



**Figure 4.** Representation of plants distribution from technological stations to final use

Indeed, the absence of an item located in a technological station has a harmful impact on a larger surface than a terminal: Consequently, more importance is given to sources than to terminals. However, a terminal may be essential for the execution of an activity in a functional space. Therefore, in this case, its importance can be increased by a score equal to that of the functional space classification in which it is installed. The possibility to increase the score is the practical inclusion of the analyzed relation among functional spaces and systems, that is summed up in the matrix of relation.

Moreover, an item relevance depends also on its effect in case of absence: if an element is essential along the distribution, it requires more attention, contrariwise, if it provides an additional/marginal function, its potential failure does not compromise the service. These elements are identified in the definition of fault chain analysis. The fault chain expression was adopted to define the correct sequence of components whose absence compromises the provision of the service, so that they can be monitored and controlled. In addition, monitoring items that belong to emergency plants have priority because their functioning is essential in case of need. Therefore, their functioning is not a constant perception. For this reason, they must be checked with more attention. Another important factor is about design characteristics of a plant. During the design stage through the introduction of backup systems, the realization of loops rather than linear distribution or the presence of repeated stations, whose capacity is enough to ensure the provision of services in main functional areas, are choices whose purpose is to have more reliable systems and to reduce the probability of failures during the functioning. These evaluations are included in the index by considering the presence of backups irrespective of their number: the only presence of them halves the criticality among items.

These factors are combined in such manner to obtain the “criticality index”. Three values are possible for IC as a consequence of possible score of each parameter that are reported in the chart: the higher it is the more a component needs attention and priority in execution of maintenance activities.

**Table 1.** Procedures for the assignment of scores to factors to calculate item criticality.

Factor	Reference question	Options	Scores
System criticality	Which is the system, the item belongs to?	Systems	See system classification
Component location	Where is the item located?	Production Distribution Terminal	+3 +2 +1
Failure effect	In case of failure, can the system provide service?	Yes No	0 +1
Function	Is a monitoring component?	Yes No	+1 +1
Back up	Has the item a back-up?	Yes No	*0.5 *1

The following formula reports how factors are managed in order to have the final item criticality, that is transformed into IC as reported in table 4.

$$\text{Item criticality} = (\text{Plant criticality} + \text{Item location} + \text{Failure effect} + \text{Funct.}) * \text{Backup}$$

**Table 2.** Transformation of component criticality into IC.

Component criticality ranges	IC
0.5 – 3.5	0.5
3.5 - 6	1
6 - 8	1.5

**3.4.2. Health state index – SS.** The criticality index gives a description of an item considering design characteristics, its function. but, other factors should be included. They are comprised in a further index referred to as “health state index”. It tries to include objective parameters such as the ageing, reliability and availability of spare parts on the market, that can define the proper moment for the substitution of it.

Components ageing is expressed as the ratio between age and expected useful life: this indication suggests the moment of substitution in order to avoid a significant decrease of component’s reliability.

Indications about expected useful life, in absence of a database about mechanical or electrical items of a healthcare facility, were obtained through consultation of manuals or literature about expected components’ useful life, consultation of insurances’ manuals (that are more precise because they give a potential expected useful life by taking into consideration installation’s conditions), finally, technicians suggestions based on their experience in such a structure. The index criticality is aggravated when it overcomes a defined percentage of expected useful life

Reliability is the ability of an item to perform a required function under given condition for a given time interval, therefore, whenever it is not subject to failures. This factor is relevant in hospitals because they can be interested in an early substitution to avoid any negative effect on more critical components: in some functional areas some components are expected to be subject to an early substitution because of their crucial role on patient health. Reliability could be measured by using two indications: an expense threshold or, in alternative, by taking into consideration the ratio among annual expense for corrective maintenance and initial installation cost.

The availability of spare parts on the market is another factor that can cause the replacement of a system or of its subsystems. Therefore, the criticality of a component, whose spare parts are no longer available on the market, is increased to suggest the replacement. These factors are gathered together in following manner.

**Table 3.** Procedures for the calculation of health state index.

Factor	Calculations	Options	Scores
Ageing	$\frac{\text{Ageing}}{\text{Expected useful life}}$	>70% expected useful life	+1
Reliability	Annual corrective maintenance	>6% initial installation costs >Threshold to be defined	+1 +1
Availability of spare parts	Are spare parts available on market?	Yes No	0 +1

$$SS = (\text{Ageing} + \text{Reliability} + \text{Spare parts availability})$$

As in the case of IC, SS, the “health state index”, is higher whenever conditions of an item are not acceptable.

**3.4.3. Priority of substitution index.** IPS. The final indication of the substitution order is the IPS index (order of substitution index), that is calculated as in the following formula. Extreme values can be 0,5 and 9: the higher the final score is, the maximum is the priority.

$$IPS = IC * SS$$

#### 4. Case study

The new maintenance management was applied in an Italian private highly specialized hospital accredited by Italian national Health Service. It covers 65.000 squared meters, that are organized in 18 medical and clinical wards, 747 beds and 42 operating theatres. The purpose is an enhancement of maintenance by including the extraordinary maintenance management in an informatic system that currently is used only for corrective maintenance. To do that, IPS, that is the combination of IC and SS, will be included in a data sheet associated to all registered components and will give information about their replacement. Criteria for spaces and systems classification were discussed with operational and health department and where coherent with those proposed.

57 are identified systems and 45 are functional spaces, clustered based on definition of functional space previously defined. Using the flow chart for systems classification 13 are emergency systems, 8 plants have more critical issues, 19 have only a critical issue and 6 have no criticalities. Based on flow chart for area classification: 13 are critical area not replicable, 8 are critical and replicable areas and 18 are non-critical areas. Consequently, a matrix of relation is extended respect to the previous based on hospitals needs and priorities.

The analysis of all installed systems was the further step of the work. The purpose was the realization of functional diagrams in order to give a description of the functioning irrespective of their physical location in the building and definition of more significant items that are part of the fault chain. Since the analysis produced many results, only for items worthy of inclusion in the informatic system both IC and SS were defined and calculated.

IC, criticality index, is the sum of criticality index of the system it belongs to, component location; effect in case of failure; item function, the obtained component criticality is multiplied by backup presence. Attributed scores to each variable are equal to those explained in 3.4.1 Criticality index – IC.

SS, health state, is the sum of ageing, ratio among age and expected useful life; reliability, comparison among annual corrective maintenance costs and initial installation costs. In particular, members of technical office fixed thresholds at 6% of initial installation cost or in alternative 5000 euro.

Moreover, technical office decided to include in this maintenance management systems also the subjectivity of technicians since their opinion can have a positive contribute in the management of maintenance activities. We realized a detailed questionnaire (for more complex items such as HVAC) or a list of questions (for simpler component), whose purpose is the assessment of spare parts availability, items safety conditions, their functioning and their aesthetic. If most of the answers are not satisfactory, the criticality of the component is further increased.

A further evolution of obtained results was the definition of three categories of items in order to choose the correct strategy for extraordinary maintenance: those for which a complete description by including ageing, degradation and questionnaire or list of questions is needed; another category is made up of component that are enough described only by ageing and degradation because surveys are useless (in example, in case of underground pipes that are not visible,); last group are those for which the analysis of SS is useless because they are minimal component and their monitoring would be more expensive than their immediate substitution.

The application of this maintenance management in the informatic system is in progress. The future development will be the correction of weights according to future obtained results. However, this approach allowed to have a recap of the current system state of plants.

#### 5. Discussion and Conclusions

Hospitals are particular buildings for which maintenance is significant. Nowadays indications about this topic are limited because of the absence of database about components expected useful life and indication about reliable reliability curved of their components. The future should be oriented towards the realization of references and database for maintenance of mechanical, electrical systems in such structures by keeping track of differences among facilities. Healthcare facilities are, indeed, of different size and can have different wards, consequently, the approach to maintenance is not the same. This could also contribute to the realization of a reference database for practical indications about reliability and ageing of items installed in these structures. Indeed, in the future maintenance will be the result of shared experience and knowledges.

However, maintenance activities should be defined after the analysis of all concurring factors: carried out activities, associated to functional spaces, and nature of installed systems. Their relation is defined through a matrix of relation that details what a functional space needs and vice versa. Thus, the strength of the new maintenance model is that it considers items based on their function and role according to specific conditions of installation. Indeed, starting from more important functional areas and their needs, going backwards, essential items can be identified and, therefore, maintained. Reported scores are an indication of the realized application but the central point of the article is the suggested approach irrespective of their correctness. Indeed, the model implementation and check phase will be developed in future.

A faster approach exists: the evidence-based design. It can be applied as well as during the maintenance planning. Indeed, the possibility to keep track about the nature of existing criticality can be interesting in the choice of maintenance strategies: if a correlation with patients' health exists, a preventive maintenance can be appropriate; if only operational and economic issues are present, corrective strategy can be accepted.

Moreover, the study showed an additional hypothetical approach to the maintenance design: a deep analysis of functional spaces and systems relation corresponds to an horizontal and more detailed maintenance plan, while an approach based on intensity of cure, referred to as vertical maintenance plan more fast and less accurate.

Irrespective of the chosen approach, the new maintenance management suggest that maintenance of system cannot be planned ignoring spaces and their function any longer.

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