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Facilities components' reliability & maintenance services self-rating through big data processing

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Abstract. The availability of big data in the information modelling of buildings can be useful to improve maintenance strategies and activities that are integrated in a digital twin. In some countries, such as Italy, tender specifications for public works must avoid any reference to specific brands and models, both in building design and maintenance services: quality levels and service-life objectives must be defined solely through performance specifications with reference to national or international standards. This could be a critical issue when considering reliability and serviceability of facility components, because there are no official methods about the ratings or measurements on the aforementioned performances. To help solving this concern, a method is proposed to broaden the scope of the big data collected from IoT applied to facility components, so as to feed a general and public database capable of normalizing data on faults and the effects of maintenance interventions, e.g. by correlating them with actual running times and operating conditions. In this way, each component on the market can theoretically feed a public and accessible database that collects reports on the occurrence of faults and the maintenance results, thus statistically processing its propensity for durability, the effectiveness of maintenance, the maintainability propensity of components as well as their reliability (e.g. by assessing the interval between maintenance interventions). In this way, a standardization of reliability, maintainability and durability performances ratings for components and serviceability performance rating for facility maintenance services could boost the facility quality design and improve the maintenance management.

1. Facility maintenance in buildings

To define maintenance, it is appropriate to refer to BS 3811:1984 and ISO 15686-1, which identify it as «a collection of operations required to keep an item in, or restore it to, an acceptable condition» [1]; this statement is necessarily linked to that of the "repairability" and "serviceability" of a building systems component [2]. This paper focuses on this type of maintenance, mainly for non-industrial buildings, where industry includes facility maintenance in the broader field of facility management, relying on the ISO 41000 and EN 15221 series of standards.

Repairing rather than replacing components supports the local economy and allows for the professional growth of maintenance workers, so much so that some European states tend to fiscally facilitate repair activities, as well as reduce the environmental impact of buildings. In fact, repairability has been found to be an obstacle to achieving a long service life even in seemingly "low-maintenance" elements that, at an accidental failure, show criticality or onerousness that recommend replacement instead of fixing. Paying attention to repair possibilities in a timely manner and accessibility of components for maintenance operations [3] could have extended their effective service life. For example, the Italian standard UNI 11156-1,2,3 design service life estimation can be conducted by factorial method (which determines the useful life in situ by correcting the service life with multiplicative factors that take into account the particular conditions in which the component is used); statistical method (which is based on the analysis of the context and the behavior of the materials in that context); engineering method (proper to design conjectures); the standard ISO 15686-7:2017, also prescribes a factorial methodology based on the indicated probability of previous failure. All these methods do not deal with attributing statistical data to a particular component (manufacturer, model, etc.), but rather to a class of components.

Facility management should rely on accurate real-time data to plan maintenance activities and facilitate decision making [4]. Especially in the case of technical plant terminals, which are numerous and distributed throughout the building, inspection and collection of chronological data would require time and labor [5] that are not always compatible with available resources [6], unless recourse is made to the opportunities offered by IoT deployment. Otherwise, mostly corrective maintenance is worked on: interventions (often delayed) are carried out to boot in response to failures or complaints [7].

The spread of self-diagnostics and the potential availability of networking would instead allow the data readily available from on-board sensors to be used to organize predictive maintenance through statistical data analysis and processing [8].

Since IoT can be defined as «the interconnection of sensing and actuating devices enables the sharing of information between platforms through a unified framework, resulting in the development of a common operating framework to enable new applications» [9] it must mainly rely on standard protocols and technologies that interface sensing, identification and recognition, hardware, software and cloud platforms, communication protocols and networks, software and algorithms, data processing solutions, etc. [10].

The framework of information made available is not only collected over time, but time (the fourth dimension) is itself a datum that can enable the objective assessment of the reliability over time of that element and of the same element's family (model) over time.

The main purpose of this paper is to propose a general method that can structure, in the continuation of the research work, applications suitable for each case where the quality requirement can be considered to be based on reliability performance. In parallel, a general method is also proposed for applications that evaluate the maintenance company, so as to facilitate the sharing of objective information also about the quality of the servicing and repair work. The proposed classification looks intentionally simple in its result (stars), but it presupposes considerable data processing work that takes into account that the data are derived from sometimes very different service circumstances of the components: often in this context "an hour of operation is not an hour of operation" and it is necessary for the computing algorithm to take into account not only the quantity in the "service state", but also their qualities.

The research, funded by the Italian Ministry of Education, University and Research, goes in the direction of increasingly encouraging the sharing of information that the network allows in order to make the prescription of quality over time and its verification more objective also to facilitate and make transparent the feedback of the requirements of the specifications in tenders for services and supplies.

2. Feeding the database: IoT; public access and national data collecting; dynamic rating scale

Nowadays it is a well-established practice to globally share product reviews, including building and facility supplies, that all e-commerce websites manage to generate a score, usually belonging to a simple stars (from 0 to 5) rating system. Although this system is useful to guide a value for money choice, nothing or very little can say about components on site reliability over time. This is because the vast majority of customers' reviews, from a time perspective, are focused on purchase and successful (or unsuccessful) installation phase and, moreover, the basis of the review is very often subjective (if something goes wrong, the reviewer is much more likely to rate, even very negatively, than in the case of normal performance).

Especially regarding facility components, it is in fact very difficult to collect in this way trustworthy data about their operation and reliability, while the point is precisely how to reliably evaluate and rank these components.

The ongoing research detected how continuous monitoring, central statistic processing and IoT sensor data collection, can be the answer: in this way a public access network database can be steadfastly fed, and also data on component faults and maintenance intervention can be normalized.

Thanks then to a dedicated ranking algorithm, it can be possible to provide a network-based dynamic ranking system to evaluate a reliability index for facility components. It could be a probabilistic rank-by-frequency algorithm which identify and tag events (precisely the occurrence of faults, maintenance alerts and requests, in this case) by the number of times they occur in the dataset and takes also into account the uncertainty of the data [11].

The output could be a real-time performance tool that ranks and compares the operational efficiency of system components over time through a dynamic reliability index, not far from Amazon product "stars", whose score is constantly normalized by the number of reviews that occur over time, although, in this case, the big data are types and frequencies of failures objectively recorded by IoT sensors, rather than subjective reviews.

It is particularly interesting to highlight a similarity with network-based dynamical ranking systems currently available for individual players or teams in several sports, where dynamics and time-changeable players' strength and ability are key objective items [12]. Thereby, a dynamic network-based ranking implies the temporal information of the data, in order to mirror the ongoing monitoring process thanks to IoT sensors, rather than crystallizing an initial situation such as a Site Acceptance Test (SAT).

3. Quality over time through design&tender specification

3.1. From model name-driven records to anonymized rankings through big data processing

As well known, Quality is the degree to which the performance of a component or service meets design requirements [13]. While the effects of warranties to end users of industry products flow through after-sales services into companies' large databases on failures, defects, and recalls, these databases remain unavailable to customers and designers, unlike those built on the Web, which, however, are voluntarily fed by the reviews (subjective and sometimes uneven in judgment criteria) of users of the products themselves.

In facts, the focus on durability, reliability and service life for building materials and components has progressively become a pivot in the design process [14]; the reliability and maintainability of a component over time is still predominantly based on market reputation and manufacturer self-declarations (and self-esteem). In addition, a number of public databases on the reference lives of building components have been initiated, for example by the AQC (*Agence Qualité Construction*, Paris) or the C.S.T.B. (*Centre Scientifique et Technique du Bâtiment*, Grenoble) and the Politecnico di Milano. They all referred to a range of components and did not focus on any one manufacturer, model or production range, due to the difficulty of having enough reliable data on each item.

Currently, with the widespread use of self-diagnostics and the network control on many components of the systems serving the building, it would be possible to synergistically and statistically more reliably process the combination of the two kinds of information (self-diagnosis and status of networked monitoring) in order to objectify as much as possible the detection and statistical processing of faults, defects, and repair action. In addition to being interesting in itself, this will provide for each component model a reliable picture of the recurrence of its failures so as to rank its reliability. By grouping reliability into classes (i.e., ranges of failure recurrence), these will be independent in use from the models that generated them and thus can become a design requirement unrelated to manufacturer and component type.

Public works in Italy must comply with the sixth paragraph of Art. 68 of Legislative Decree No. 50/2016 [15] which states «Technical specifications may not mention a specific manufacture or origin or a particular process characteristic of the products or services provided by a specific economic operator, nor may they refer to a trademark, patent or a specific type, origin or production that would have the effect of favoring or eliminating certain enterprises or certain products.». Thus, such a project and tender must not contain any reference to manufacturers' names, brands and models of equipment; unlike the projects for the private market, where the designer's experience or the product's reputation can help in ensuring long-term quality, it would be very useful to have an independent rating of product reliability and maintainability, such as is the case for the energy efficiency class for electric motors. In this way, designers can specify the desired reliability without referring to a specific manufacturer or model, but only citing the reliability class they feel is correct for the project.

Such a kind of ranking can be accomplished by processing the big data collected by the network that shall interconnect via web the on-board sensors and diagnostics of facilities components to an open central database, thus providing a dynamic real-time ranking system.

3.2. Working life in building facilities components

Quality over time cannot be specified through service life requirements (component life) alone. We need to think about quality of service in relation to the continuity of service required at the design stage (reliability), the amount of maintenance required to achieve it (maintainability), and then the resources to be allocated during the operation phase. In addition, a redundant system (e.g., a chandelier with many bulbs) can have an adequate operational life even if the reliability of the repeated elements that constitute it is short, because they will not all fail at the same time and the service can continue at most with a modest decay in performance: the "chandelier with many bulbs" can thus be judged durable, though not reliable, if its maintenance is reasonably easy, inexpensive, managed with proper scheduling, and if its spare parts are available for its expected lifetime. For this reason, estimated service life databases are very useful for estimating and scheduling maintenance costs, not for specifying quality over time as effectively as possible; that is why a new methodological approach based on IoT and self-diagnosis can help tender and design requirements.

Coming to the major facilities components, the advantage is that today's widespread use of their electronic (rather than pure-electrical) control and the built-in or easily embeddable self-diagnostics could help collect a lot of specific data in real time if they were networked stably (as is the case with many household appliances) as in Figure 1. IoT can hence help to tag the real behavior of each facility component and thus feed with enough data a public database on their real reliability and maintainability, overcoming the current situation where designers and construction managers could only rely on market reputation or manufacturers' claims, whenever applicable.

4. Specifying Quality over time: from Reliability index to Reliability class

Any building fittings design must aim for quality of service over time, which is usually identified by the Expected Service Life (ESL), that is, the period in which components can be used for their intended purpose with only scheduled maintenance, but without the need for substantial repairs. In any case, service continuity is not mentioned here: for example, a software restart after a crash is not a substantial repair (the user can do it himself), but it can also severely affect service continuity, especially if it is a recurring defect. The ESL parameter can then be considered inadequate to express quality-over-time, which is rather a mixture of reliability (the ability not to fail) and maintainability (the ability to be repaired).

As a matter of facts, in construction design and procurement it is almost impossible to specify the maintainability and reliability requirements for facility components because at present there are no standardized methods of measuring or classifying this performance. The spread of IoT suggests the structuring of a method that builds on the collection of big data and processes it for real-time classification of component reliability and durability.

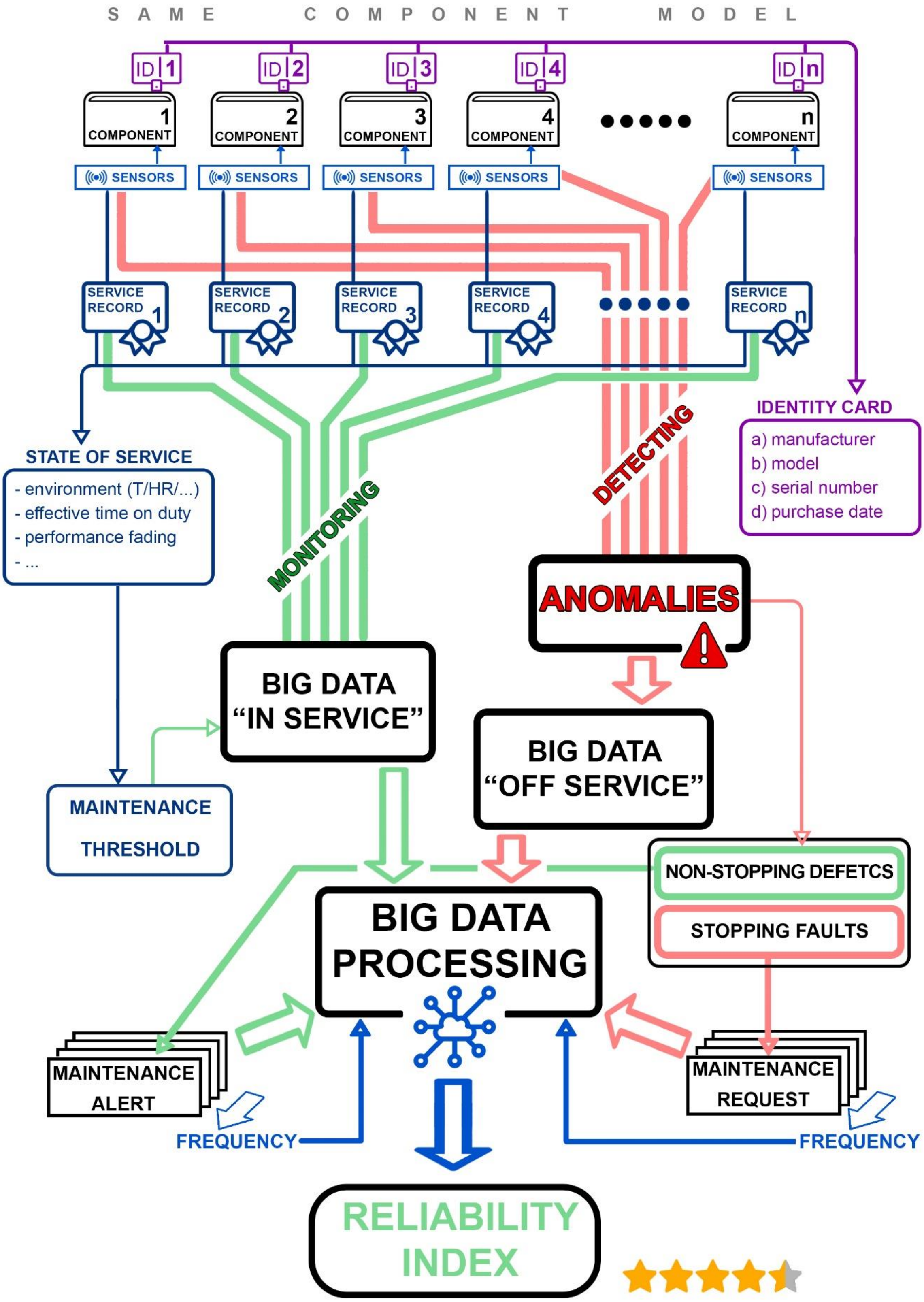

Figure 1. Big Data flow for reliability index.

For example, the failure rate of a motor can be affected by such factors as insulation deterioration, wear of sliding parts, bearing deterioration, torque, load size and type, overhung loads, thrust loads and rotational speed. At the time of failure, the date, time, electrical parameters and performance are recorded by the sensors and sent via the net to the data processing unit, which compares them with the original ones recorded at the beginning of the motor's operating life: everything is then stored in an open-source database, together with the component's identification sheet (brand, model, serial number, manufacturer, year of purchase, place of installation, designed performance, designed environment, temperature and R. H. under normal service conditions, etc.).

The reliability index must be determined for that certain motor (that serial number and model) by considering the elapsed time between failures, their nature (shutdown or nonstop failure) and their frequency. Then, all reliability indexes collected in real time for the same motor (identical model but different serial numbers) must be grouped and statistically processed to obtain the reliability class ranking, as suggested further on.

In this way, the reliability class can be finally specified in the project as a requirement and can be evaluated in the bidding process as a key performance. The highest is not always the best: lower reliability classes should be applied in case of shorter designed life or better class of maintainability (e.g., a water faucet in an unattainable alpine hut or in an industry that has its own permanent maintenance service require very different approaches).

4.1. Managing big data for reliability assessment

In addition to processing "in-service" big data to properly plan the maintenance schedule, "in-service" and "out-of-service" big data can be the basis for structuring the reliability assessment algorithm. All these data can come from integrated self-diagnostic boards, if properly programmed and net-connected, and they can be processed applying the method drafted hereafter.

Considering any type of building system component (such as a light bulb, a fan-coil unit, etc.), a local integrated diagnostic board is programmed so that a microcontroller orders data from the sensors according to their importance and arranges for their storage first in the local database and then transmits them, if it assesses them as significant, via Wi-Fi connection to the cloud [16].

In this context, big data processing is divided into two stages, the first performed locally by the microcontroller embedded in the self-diagnostic board, the second by a central processing unit that then feeds the open-access reliability database.

4.1.1. First stage: screening each Serial No. for significant data. The first stage screening is locally performed by the MCU board and labelled with the specific serial number and component model. In order to collect meaningful data for centralized reliability assessment, local programming and processing is required at first so as not to overload the network with a huge amount of unnecessary data. So in the first step of this first stage the logical board embedded on the component is programmed to discharge all the completely blown parameters (i.e. statistically inconsistent values); then a second step is taken to screen the remaining data: all those that are out of range contextually with anomalies in external parameters (such as water, power, temperature, humidity, etc. that results outside the design specifications) are rejected because they probably come from an environmental frame that is distorting the performance frame and cannot actually indicate a defect in the device. Finally a third step is performed, discarding all temporary anomalies (e.g., lasting less than a few seconds) to focus on lasting anomalies only and categorizing them in stopping and non-stop defects. In this way, most of the records collected by the sensors remain in the local memory board, and only those that are significant for anomaly tagging are sent via the Net to the central processing unit and the elaborated to feed the open-access database, all that without overloading the net.

4.1.2. Second stage: statistical processing of same model's anomaly data. This second stage is based on the record filtered and then sent by all the local embedded microcontrollers net-connected to the central processing unit. Each record consists of the component's category (CO), manufacturer's name

(MA), model name (MO), serial number (SN), and date of purchase (DP), all of which constitute the component's "identity card", to which are added the date and time of fault detection (TF), type of fault (KF), and the entire sensor output at that time (SO).

Central data processing must first break down component seniority records (time elapsed since date of purchase) to show general indices by age range, and then weight the service hours by real service conditions (records in each component's "Service Status") to obtain a "normalized age". The following steps are performed for each age interval.

The first step is to divide the stopping defects from non-stopping defects through the KF tag; the second step is to identify and group for both groups all data (SO) related to the same component model (MA and MO). The third step is to calculate the frequency of stop failures (FS) and non-stop failures (FN) up to a 5-year base. The fourth step is to look for whether there are similar SNs (e.g., the same character string for more than 66% SN than the first serial number showing the fault) of the same model with the same fault with a failure frequency higher than the general average failure frequency for that component category (GFF): in this case, a specific alarm is issued (referring to CO, MA, MO, and SN interval) and all those records are discarded in subsequent statistical calculations of the GFF (which is by component category, not by MA and MO specification), so as not to distort the GFF by producing some out-of-specification batch: the procedure is thus an iterative cycle, which must be stopped when no other out-of-specification batch is determined. On the other hand, deleted records are routinely taken into account to calculate the FN and FS of the specific model.

4.1.3. Reliability star rating. FN and FS being calculated, the frequency of all shutdown failures of any nature is an indicator of service continuity propensity, while the frequency of non-shutdown failures of any nature is an indicator of service quality propensity: a further development of this research path is to implement other ratings in the conceptualization of the open access database.

At this stage, the reliability index is a weighted average (e.g., half and half) of the above two parameters over the five-year period considered (age group specified) and inferred from an annual basis, if necessary. It is to be determined in two different ways: (i) for each CO (component category) for use in design requirements, and (ii) for each component model (MA and MO) for use in Construction manager's inspections and tender specifications.

The reliability index thus calculated is useful for expressing a reliability requirement at the design stage without referring to a specific manufacturer or model, instead requiring a reliability class expressed from 0 to 5 stars. In this conceptualization of the research, three stars means that average reliability is required (GFF +/- 20%); four stars requires a reliability index 21 to 66% lower than average; five stars requires a reliability index 67% lower than the average GFF index for that component category (CO). Conversely, two stars represent a reliability index that is 21 to 33% greater than the average GFF; one star means the reliability index is 34 to 66% worse (greater) than the average; and a zero-star rating is given when the reliability index is 67% greater than the average.

On the other hand, a reliability index calculated for each component model is very useful in demonstrating the fulfilment of the designer's requirements in the tender specifications or the construction manager's inspection. Each component model is assigned a class of 0 to 5 stars, based on the deviation of that model's reliability index from the GFF (category average), similar to the previous design evaluation: if that component's reliability index falls within the range of +/- 20% from the average of the category to which it belongs, it is assigned 3 stars; if it is in the range of 21 to 66% lower than the GFF, it is assigned a 4-star rating; if it is 67% or more lower than the GFF, it is given a 5-star rating. Conversely, if it is greater between 21 and 33% than the average reliability index of the GFF category, two stars are awarded; if it is greater between 34 and 66%, one star is awarded; and finally, if it is 67% greater than the GFF, no stars are awarded.

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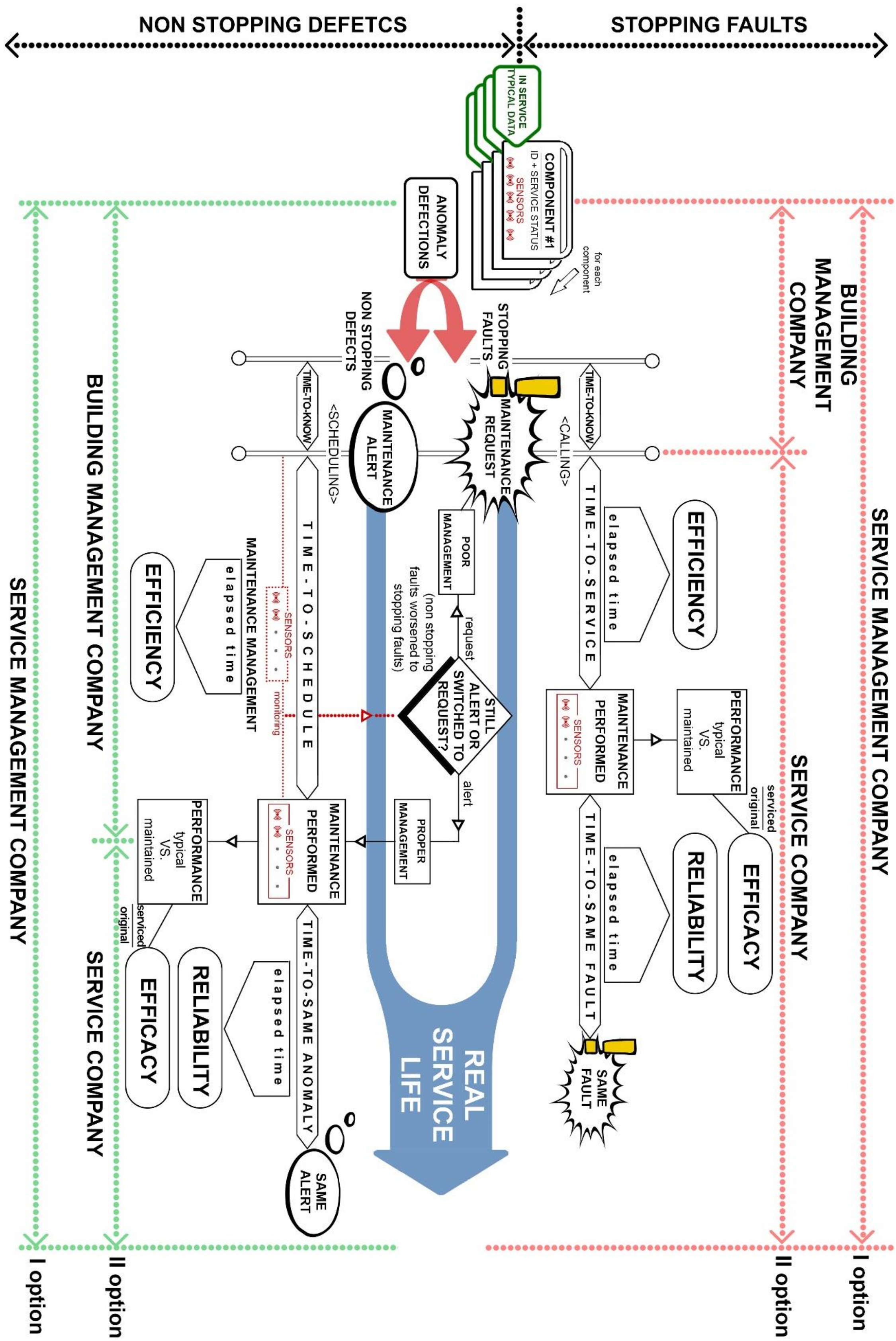

Figure 2. Data flow and timeline for maintenance companies rating.

5. Quality rating for Maintenance Service

Once the deployment of networked self-diagnostic systems has reached sufficient levels, the big data collected in real time can also be implemented with the data coming from Service technicians (scheduling, onsite working periods, spares, etc.) which can be used to rate the maintenance service and the maintenance management in building facilities, according to the conceptual diagram in Figure 2.

Two options are highlighted in that diagram: maintenance service can be performed by the same operator in charge of building management (SMC, Service Management Company) or the building management company can outsource it to another service-only operator (SC, Service Company).

In this research program, a service management company (SMC) is defined as the operator in charge of both the operation and maintenance of the building: therefore, he is also responsible for implementing net-connected self-diagnostics on the facilities components and proper data management or other comparable system that can assure him of all the necessary information in due time. In fact, any inefficiency or failure due to lack of situational awareness is his responsibility. In the case of SMC, the Time-to-Know (TTK) interval (the elapsed time between the occurrence of an anomaly and the time when it generates a service call) must be added to the Time-to-Service (TTS), and their sum contributes to the evaluation of Service efficiency.

A service company (SC), on the other hand, is an operator who is only responsible for maintenance, without being responsible for the monitoring or implementation of the net-connected self-diagnostic system and the time elapsed between the occurrence of defects and the call for service. In this case, only TTS should be considered to evaluate the efficiency of the service company.

The method of this research bases the evaluation of maintenance service quality on three measurable data sets: (i) the Time-to-Service (the elapsed time from service call or alarm to arrival on site), to assess service efficiency; (ii) the Time-to-Same Fault (the time interval for the same fault on the same component), to assess the reliability of the company's service; and (iii) the ratio of performance after service to original performance (i.e., how much the service has recovered original performance levels) to assess servicing efficacy.

5.1. Service efficiency assessing

The evaluation of the company's service efficiency is based on the average value over a time interval of up to ten years of Time-to-Service or Schedule for all SCs, while for SMCs the average is calculated on the sum of Time-to-Service or Schedule with Time-to-Know: like all average values in the database, these are dynamic values, so they will increase or decrease depending on the real performance of the companies that actually perform maintenance and are recorded in the database.

The determination of service efficiency must be handled separately in the two cases of Stopping faults and Non-stopping defects, because the time between the onset of the fault and the intervention is desirably very short for Stopping faults, while it may appropriately be much longer between the onset of the defect, or the crossing of the alert threshold, and the date of maintenance scheduling. In the ongoing exposition of the method, in the former case TTS is to be read as Time-to-Service; in the latter case it should be read as Time-to-Schedule.

For Service Companies (SCs), the comparison of the TTS of the individual intervention, recorded by the sensors, or by the devices for scheduling and managing maintenance interventions, with the dynamic average calculated by the central database: if it is at least 25 percent less than the average TTS, the Company earns two stars; if it is more than 25 percent greater than the average TTS, the Company earns no stars; in all other cases (specific TTS between 25 percent more or less than the average) one star is awarded.

For Service Management Companies (SMCs), the comparison is made, with identical objectives, on the basis of the sum of the TTS and TTK of the individual maintenance, also recorded by the sensors, or by the devices for scheduling and managing maintenance interventions, with the dynamic average calculated by the central database of the sums of TTS and TTK: again, if the sum is at least 25% less than the average of the sums, the Company earns two stars; if it is greater than 25% the Company earns no stars; in all other cases the Company earns one star. In addition, in cases where the service intervention involves non-stopping defects, the service schedule may be so late as to allow time for the anomaly to evolve into a shutdown fault: again, no stars are assigned.

5.2. Service reliability assessing

The evaluation of the company's service reliability is based on the comparison of the Time-to-Same Fault (TTF) of a specific maintenance intervention and the average value, over a time interval of up to ten years, of the TTF from all SCs and SMCs indifferently, calculated dynamically on all records in the open-source central database. The Time-to-Same Fault of the individual intervention is detected by the software on the local CPU of the self-diagnostic board powered by the embedded sensors and sent via net to the central database.

As above, if the specific TTF is at least 25 percent higher than the average TTF value, the Company earns two stars; if it is less than 25 percent higher than the average TTF, the Company earns no stars; in all other cases (specific TTF between 25 percent higher or lower than the average) one star is awarded.

5.3. Service efficacy assessing

The evaluation of the efficiency of the maintenance intervention is done through the ratio of the after-servicing performance to the original performance stored in the central database and referred to that serial number (SN) and model (MO). Only the performance that resulted in the detection of anomalies by self-diagnosis is considered.

If the specific ratio is above 95 percent, the Company earns two stars; if it is less than 80 percent, the Company earns no stars; in all other cases (that is in the range between 80% and 95%) one star is awarded.

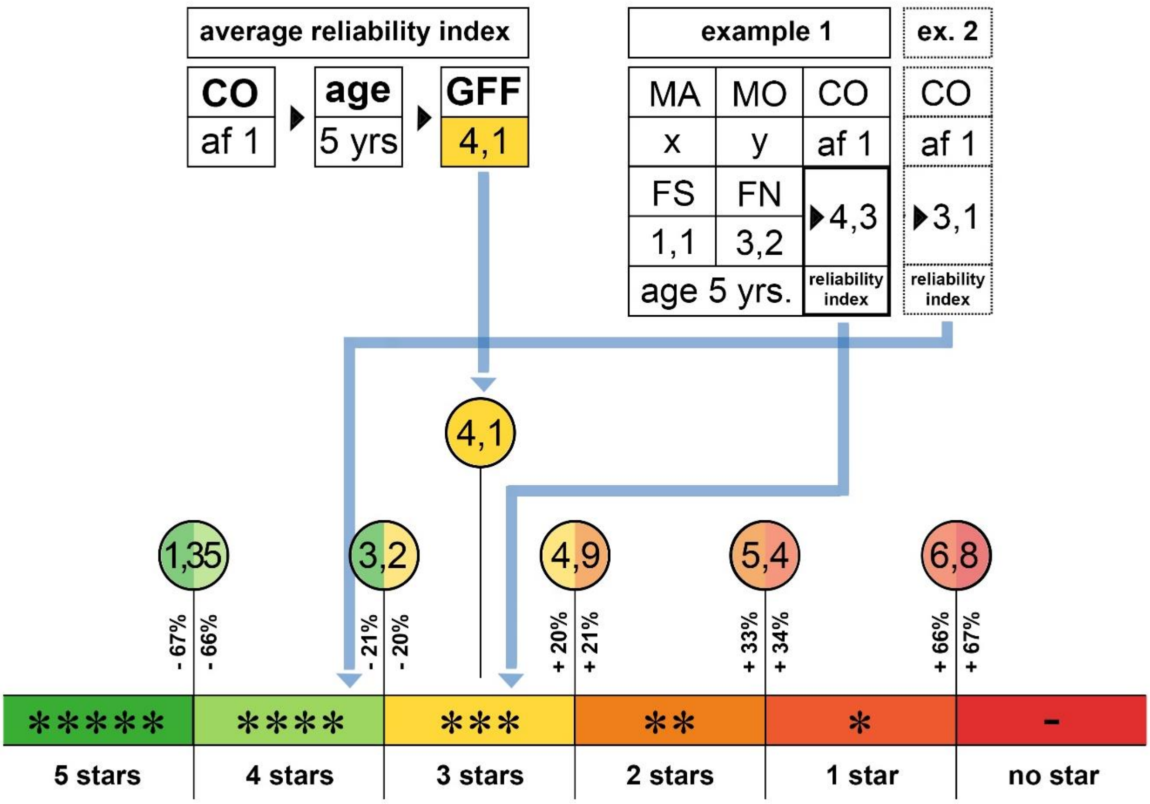

Figure 3. From General Average Failure Frequency to company reliability rating.

5.4. Maintenance Service Rating

In this method, the service or service management company is evaluated by assigning stars, which are the sum of the stars obtained in each of the three parameters: Efficiency, Reliability and Effectiveness. Each of them, as shown above, can assign a maximum of 2 stars and thus each Maintenance Company and each Maintenance Management Company can have a total rating from 0 to 6 stars.

These ratings should be matched to the Company's name in the open-access database in order to aid the selection of maintenance operators and, when accepted by the Public Administration, can be added to the requirements specified in public tenders for services and supplies.

6. Conclusions

The methodology outlined above is intended to propose to the scientific community and private public commissioning bodies a research path to overcome the current unavailability of accessible data on the reliability of plant components from the anomalies detected during maintenance work and recorded with the intelligent gadgets, smart mobile devices, single board computers, and other sorts of sensors and actuators are examples of typical IoT devices.

Within this framework, the future development of research involves moving to the application of the conceptualized method to the definition of algorithms for rating each category of component: these must be specifically developed for each type of component and must be validated through an adequate information-gathering phase in the field, after the deployment of relevant monitoring and data collection systems, including by maintenance companies.

The main innovative result of the methodological research carried out was to make available a system for rating the reliability and quality of components over time, the results of which will be compatible with Italian legislation in the field of public works, which does not provide for the possibility of indicating the names of manufacturers and models of components in the project documents or in the tender offer.

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