FUSE-IT: Enhancing Critical Site Supervision with Cross-Domain Key Performance Indicators

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***Abstract*—Performance and compliance objectives have become crucial for critical sites. Balancing security, energy and costs with operational objectives is the current main challenge for critical site administrators. While current systems are not integrated enough to provide an overall view of the site performances on such targets, the FUSE-IT project intend to propose a new paradigm: the convergence of monitoring on energy, building and facilities, cyber and physical security, and ICT will leverage critical sites activities and offer new opportunity in the detection of threats or savings. In this paper, we detail the first building block of the FUSE-IT concept which lies in the definition of cross-domain (i.e. on energy, security, ICT and facility) Key Performance Indicators (KPIs). These KPIs are the main decision variables for an enhanced Decision Support System (DSS) meeting the next century impediments of critical sites.**

I. Introduction

Critical Sites are constantly under the threat of security violations, either on their physical or on their IT infrastructures. In the meantime, their buildings get more and more intelligent with the deployment of smart sensors. Having a sustainable, reliable, user-friendly, efficient, safe and secure Building Management System (BMS) is thus becoming a major challenge.

The next-generation Smart BMS must be able to derive Key Performance Indicators (KPIs) for all these four domains, using data from a common information base. The performance cannot be evaluated in silos as it is traditionally done to facilitate reporting to different stakeholders based on their desired view of the information. An *holistic performance evaluation* process is needed to leverage on the existing views to provide high-level analysis and awareness. Such a process encompassing *cross-domain KPIs* is the core component of the Smart BMS proposed by the FUSE-IT project, which targets the evaluation of the *four domains* a critical site administrator aims to supervise: the Energy supply and efficiency (micro-grids, energy monitoring, back-up, storage, etc.), the Facility and building automation (heating, ventilation and air conditioning, lighting, etc.), the Information and Communication (local area networks, indoor wireless, network operation, etc.), and the Security and safety (fire detection, anti-intrusion video-surveillance, network access control).

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In this paper, we define the concept of *holistic performance evaluation*: how next-generation of Building Management Systems can integrate constraints and objectives of multiple domains to improve the performance objectives (i.e. in terms of costs, security, compliance, stability, etc.) of a critical sites. To this end, we focus on the definition and processing of *multi-domain Key Performance Indicators*: 1) How to get the relevant knowledge for an efficient, effective and holistic Building Management, 2) How to use the knowledge to provide intelligent and secure management and control for a smart BMS, 3) How to use the knowledge and the intelligent and secure management to foster buildings management into Smart Grids context and foresee new business models.

Section II presents some related works and the cross-domain KPIs as proposed by the FUSE-IT consortium. Section III gives some insights on how existing Building Management Systems (BMS) operating on critical site can move to Smart BMS with holistic performance indicators. Section IV proposes novel methods of multi-criteria decisions aid to realize the holistic performance evaluation using cross-domain KPIs. Section V describes how such high-level analysis can be retro-propagated as corrective actions on the Smart BMS using root-cause analysis or optimization approaches. Finally, section VI concludes the paper.

II. FUSE-IT Cross-Domain KPIs

This section first presents the related work (sec. II-A) on cross-domain evaluation and defines the concept of holistic performance evaluation proposing some cross-domain KPIs.

A. Related work on Cross-domain approaches

In their seminal work on research challenges for the Security of Control systems, the authors of [1] have identified the satisfaction of operational and security goal as a major requirement of control systems. We claim that, at the scale of critical site where many control systems co-exist, the Building Management System have to go smart by introducing holistic performance evaluation through cross-domain KPIs. The authors of [2] introduce the needs for cross-domain information sharing of relevant building data, as improving operational strategy and performance evaluation. They also discussed the benefits and challenges of cross-domain information sharing data in the building.

In [3], the authors develop an approach of Linked Data to manage cross-domain data integration (data input come from different sources). The goal is to overcome interoperability problem, to drive the management of scenario according to a Business Process Model [4] and to use real-time scenarios for Complex Event processing [5], [6]. The work of [5] particularly illustrates the potential of cross-domain approaches in scenario modeling demonstrating the benefit of leveraging on different information silos within organizations and demonstrates the benefits of optimization.

B. Holistic Performance Evaluation

1) Building Efficiency: Building efficiency targets the monitoring of the building performance according to its needs and its resources. Figure II-B1 illustrates which KPIs should be involved. Hence, KPIs expressing the needs on comfort, but also performance, and characteristics are required to evaluate the efficiency of the building. Resources are essentially energy related. The goal is to capture how a decrease of the resources impacts the performance of the building, and conversely how an increase in the demand and performances affects the resources. This high-level KPI also involves cost information since increase in resource usages has to be balanced with operational or maintenance costs.

2) Holistic Security: With Building Efficiency, holistic security is one of the main targets of the FUSE-IT project. Holistic security aims to federate security information from Cyber and Physical security monitoring but also from Facility Management domain (which traditionally encompasses safety) and ICT security. The goal there is not only to have a daily monitoring of the security systems but also to collect security events and metrics from these 3 domains. While security events help to analyze whether an attack is on-going or not, metrics such as risk-related ones can be helpful to derive a threat analysis. The obtain threat level can then be balanced to remediation costs and/or prediction on the attack sequence.

3) Compliance: Compliance to norms or standards is a concern for energy, facility management and security. In the field of ICT, while there are norms and standards, their enforcement mostly comes from the other 3 domains: for instance national security agency can forbid some protocols or impose norms on cryptography keys. Hence, to capture the compliance in the ICT domain, we advocate to focus on environmental and health impacts which encompass KPIs on noise and electromagnetic pollution specific to the ICT domain.

4) Cost Efficiency: Having a holistic view over the 4 domains which are used to be considered in silos can also be helpful for cost monitoring. Obviously, cost efficiency is a concern for all the 4 domains. Hence, having a global cost view could help the building administrator to define its investment and maintenance policy.

III. Leveraging on Data-driven Building Management Systems

In this section, we demonstrate how existing Building Management Systems can leverage on data-driven evaluation to a holistic view of the performance indicators.

A. Situational Awareness

Situational awareness is defined as having all the information relevant to a complex system when taking a decision. Historically, this concept is mainly taken from the perspective of a human decision maker [7]. Recently, technological advances on computing power, allowing processing events or data collected from many sources simultaneously using data fusion techniques, resulted in the emergence of self-aware and self-managing complex systems [8], [9]. Concept of Complex Event Processing (CEP), first introduced by David Luckham [10], provided an event-driven approach to situational awareness. This approach processes patterns of events, enriching the events included in the pattern with related information and making sense of the pattern using a rule-based approach taking into consideration time and space domains of the occurring events. CEP has since gain popularity among IT solution/service providers like IBM and Oracle and still continuing to gain popularity.

Smart Building Management Systems will profit from the use of CEP as the core for detecting actionable situations in all four domains (security, facility management, management user interface and ICT). Facilitating rule authoring and execution in the context of CEP are the primary concerns. The KPIs for situational awareness primarily depend on defining the model of relations between different domains and the capability of creating a common dictionary to enable rule authoring for domain experts from the different domains. Creating such a common language leads to define the executable rules that can deal with cyber-physical aspects of the BMS. This can be possible through, for instance, the creation of contexts that can include events from both ICT domain and physical domain (using sensors).

B. Enhancing data with web sources

The concept of Linked Data use the Internet data as a global knowledge base for a system. The authors of [3] present a general process of data integration from different systems, that feeds a knowledge database, and manages feed-back for corrective actions. The authors of [2] present a holistic building and model the implications of connections across systems.

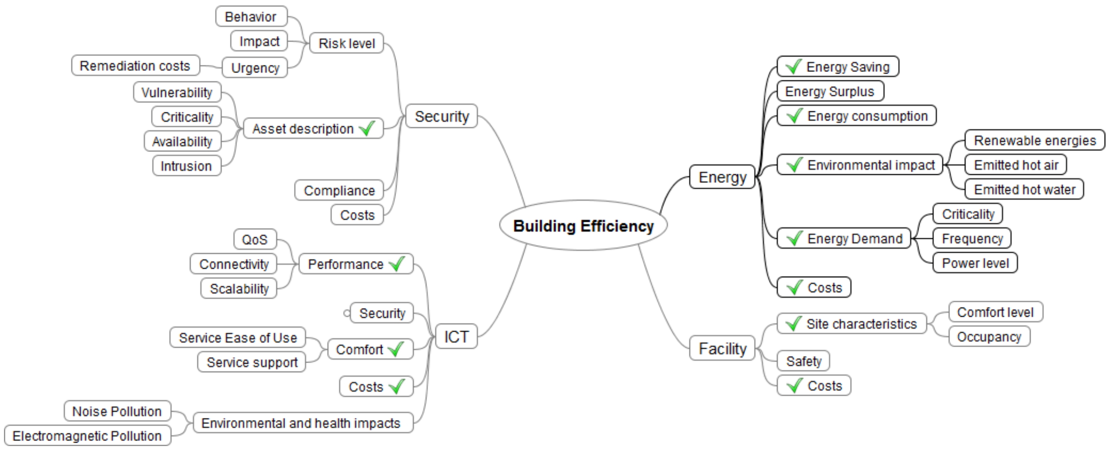

Fig. 1. High-Level KPI on Building Efficiency, the involved KPIs are green checked: Energy Saving, Energy consumption, Environmental Impact,etc. When a group of KPIs is green checked, its sub-KPIs are involved

They explain that Linked data provide a mechanism through which information silos can exist in a homogeneous and interconnected format, and they present their process of data integration including different sources such as BIM (Building Information Model) and SCADA (Supervisory Control And Data Acquisition).

In [6], the authors use an example in building energy consumption to propose a method to collect data based on linked data solutions. They observed that the generation and publication of Linked Data are intensive engineering processes that require high attention in order to achieve high quality.

C. Data gathering for Cyber-Physical Systems

The work led by the NIST Cyber-Physical Systems Working Group [11] gives a broad picture of Cyber-Physical Systems and presents a shared view of key concepts and particularly the concept of "aspects" (Functional, Business, Human, Trustworthiness, etc.) that extend the needs of data gathering and transformation. Such aspects are crucial for critical sites and need to be captured by KPIs and related metrics. One important issue to capture these aspects is data interoperability.

Data interoperability actually bring several concerns: data and meta-data, identification, data quality and provenance, governance, privacy and cyber-security, and reliability and assurance. Moreover, data interoperability must be addressed within the context of domains. The NIST working group [11] present the challenges of data integration complexity and Cyber Physical System boundaries as the followings: data fusion and interaction from multiple sources and systems, tracking of complex data path, privacy protection, predictive analytic capabilities and information quality. Their effort in featuring the data aspect is to provide a sound underlying description and standard basis that simplifies and streamlines the task of understanding cross-domain data interactions. In particular, the NIST WG [11] recommend that Cyber-Physical Systems use an energy efficiency index to comply with operational conditions (i.e. availability, reliability parameters and cost, cross domain application, etc.) when performing re-configurations or re-scheduling. Finally, they stress the importance of time. Accurate time-stamps are required for prediction, root-cause analysis but also for legal or regulatory reasons.

The experiences held at DERI [3], [11] rely mainly on the development of data models which connect different silos of information through common context. This approach could be applied to a set of well defined ontologies with linked data to provide a cross-domain data model for KPI development.

IV. Holistic analysis of KPIs

In this section, we emphasize how Multi-Criteria Decision Aid (MCDA) can process multi-domain KPIs. We also consider some previous works on decision-making using such indicators and propose extensions for cross-domain evaluation.

A. Theoretical foundations of Multi-Criteria Decision Aid

A criterion is a qualitative assessment of the satisfaction or unsatisfaction over a given attribute. This given attribute can be quantitative. The corresponding criterion will set a scale of preferences over the attribute values. Note that, before determining the scale, one should wonder what the metrics which participate to the criterion are. Building the set of preferences leads to define a utility function of the attribute that both to normalize the criterion but also to make criteria commensurable.

When metrics and criteria are identified, a global synthesis should be drawn out to evaluate alternatives (i.e. entities carrying on the attribute values). In MCDA two approaches are usually considered: the Compare and Aggregate (e.g. voting systems, outranking methods) and the Aggregate and Compare. In the first case one seek to first identify local orders (thus facing the Arrows impossibility theorem) and then to aggregate them with possible uncomparability. In the second case, different type of aggregation functions exists. Some functions such as the Choquet Integral and the Generalized Additive Independence can capture interactions among criteria (substitution or compensation). Table I summarizes the Pro and Cons of these approaches.

Method	Pros	Cons
Pareto Dominance	Cautious method: Very basic assumption Does not need further time to analysis interactions among criteria	Limited to 2 or 3 criteria Hard to discriminate alternatives Leave the choice to a human being
Weight Function	No uncomparability Weight of each criterion determined by definition	Does not capture dependencies among criteria No gain in elicitation time
Choquet Integral	No uncomparability Capture interactions among criteria and hierarchical view Straight-forward interpretation and explanation	Elicitation time can be important Require to be able to learn locally the interaction
GAI	No uncomparability Lower elicitation time Global learning of complex interactions	Non straight-forward interpretation and explanation

TABLE I
PROS AND CONS OF DECISION AID METHODS

B. Multi-criteria Decision Aid for building efficiency

A lot of work has been realized in the application of Multi-Criteria Decision Aid to energy problems (see the survey provided by [12], [13], [14]). Still, the application of more advanced tools like the Choquet integral and the GAI frameworks remains to be done. An application of the Choquet Integral has be realized by [15] to the restart of power systems. Other applications are on site selections for different energy source plant [16], [17]. In [18], the authors described a multi-objective approach for intelligent energy management in a micro-grid. They use two objectives functions, each of them being weighted sum of multiple attributes. The first objective function is a cost function including fuel consumption costs, electricity costs, revenues from the sold electricity and maintenance costs. The second objective function is on emission factors including differentiation according to the type of emissions (NOx, CO2 and SO2). Such an approach could benefit from the multi-criteria function to include considerations on end-user comfort and weighted them according to the importance given to the satisfaction of one rather another (for instance if some emission factors are more harmful than others, if emissions are more important than end-user comfort, etc.). Finally, another dimension of the problem lies in the uncertainty of forecasting KPI values. Multi-criteria models can capture uncertainty and propagated to the synthesis.

C. MCDA for threat analysis

MCDA is particularly well-designed for risk assessment model. Because threat assessment models are critical and often confidential, the literature is not large on the topic. However, some authors provided example of models in the security field. The authors of [19] describe an approach to combine risk assessment and MCDA for environmental emerging threats. The authors of [20] describe an application of the ELECTRE method to risk classification for IT attacks. More recently, the authors of [21] provide an example of MCDA application combined with the Quadruplet risk methodology for Homeland security. Still, they do not provided the criterion their used unless very high-level one. Hence, to use such methods for FUSE-IT, partners would have to develop their own test-case models which can be time consuming and require expert interviews. Still, the approach might be easier to deploy for sub-cases of the FUSE-IT system.

D. MCDA for ICT evaluation

MCDA helps encompassing ICT KPIs for: the deployment of network and sensors element according to specific context and requirements, the configuration of network elements given current traffic matrices and/or forecast of traffic, and the monitoring of the performance of ICT elements providing some global overview.

Among the existing application of multi-criteria decision functions to ICT problems, we can cite the work of [22] where the authors propose a genetic algorithm coupled with a multi-criteria function to choose the most satisfying composition of network and cloud services among a set of network and cloud service offers. Such services can be used for the support ICT Cloud Services for critical sites, ensuring both Quality of Service and Security objectives.

V. USING KPIS FOR THE SMART, SECURE AND HOLISTIC MANAGEMENT OF BUILDINGS

A. Cause-effect analysis

An important component of decision making is cause-effect analysis that identifies cause-effect relationships among data. In addition, understanding complex systems such as CPS (Cyber-Physical Systems) requires a holistic approach and method that relies on the analysis of huge amount of data in particular time-series data. To capture the rate and dynamics of problems or to detect anomaly, it is necessary to map these data to graphs modeling the relationships between the system components. Then, performance indicators can be applied to such models to monitor the system.

The root-cause analysis developed in the NRG4CAST project[1] lies within a general architecture with applications dedicated to gathering raw data with sensors, to specific applications in their analytic platform composed with data cleaning and data fusion, root-cause analysis and prediction modules. In the root-cause analysis module, the authors present the transformation of data into a state graph of the system with corresponding transitions. Such a graph enables many applications: clustering of data for modeling, anomaly detection, root-cause analysis, proactive anomaly detection, and evolution in the future with error estimation. Their approach is based on an algorithm to trace back the transitions through a model with

[1]http://demo3.nrg4cast.org/deliverables/m24/D4.3 Root Cause Analysis.pdf

associated calculation of probabilities to reach a final end state. In case the end-state is a failure, an anomaly is detected.

The authors of [23] demonstrate how KPIs of the energy domain can benefit from root-cause analysis and the Ishikawa's approach in particular. One can observe from fig. V-A how the authors of [23] have tracked the impacts on a global energy consumption KPI involving the main manufacturing states of a production process. To give some insights on how critical sites could use such approaches and enhance them we have added on fig. V-A some "Security" causes to the energy consumption. Of course, dedicated studies taking into account the site peculiarities must take place to capture in-depth the elements impacting energy consumption.

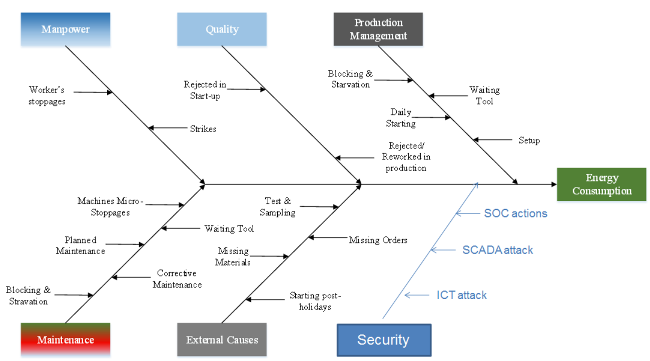

Fig. 2. Ishikawa diagram for Energy KPI inspired by [23]

B. Using KPIs in BMS Optimization and Management

In the current context of power systems, a BMS needs to use adequate methodologies to act as a player in a smart-grid and to foresee new business models, such as FUSE-IT proposal of *Building as a Microgrid*. There are a lot of challenges arising from this: dealing with the unpredictability of renewable sources, taking advantage from load flexibility, collecting and managing real-time data in a secure way, and addressing system degradation in case of security breaches. We believe that these challenges need to consider cross-domain KPIs, in a dynamic and real-time way.

Generally, the main goal for the energy management systems is to make the grid behave intelligently according to an external observer. Furthermore, it is crucial that such systems are scalable (computing features are usually poor) and remain stable when any eventuality, which provokes changes in the microgrid topology, is produced (i.e. device that stop working, plug-in/out devices, etc.). A way to reach these goals is to work with systems that operate from a distributed point of view. This means that control is not done from just one node with global view (centralized system) but it comes from a collective and cooperative behavior among different nodes (decentralized system with distributed control).

Multi-Agent Systems (MAS) are approaches that reach a collective intelligence by using different individuals called "agents". An agent can be considered as a software component that is autonomous (controls its actions and may take

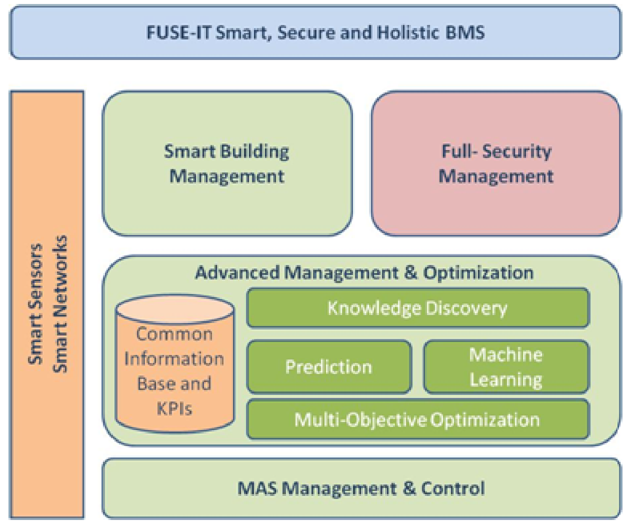

Fig. 3. FUSE-IT smart, secure and holistic management.

decisions), proactive (may take initiative besides reacting to external events) and has some social skills (interacts with other agents to achieve its goals). Moreover, in the last decades, multi-agent systems have been widely used to provide intelligence to distributed systems. Instead of developing a system with components able to perform just some tasks, agents are implemented in order to reach specific goals. Consequently only tasks that help to achieve these goals are executed. Moreover this approach makes more intuitive the modeling and developing of distributed systems as it is closer to the human thought. Thanks to these inheriting properties, part of Smart Grid researchers considers that multi-agent systems are suitable approaches to deal with energy management in microgrids. In fact there are several Smart Grid-related papers in literature, like the surveys of [24], [25], which do count with intelligent agents systems as the right technology for Smart Grids. In the smart grid and micro-grids operation paradigms, consumers can be seen as an energy resource with decentralized and autonomous decisions in the energy management. It is expected that each consumer will manage not only the loads, but also small generation units, heating systems, storage systems, and electric vehicles.

The FUSE-IT project proposes a set of knowledge discovery, optimization and forecasting techniques to be used by a multi-agent based control system for the intelligent management of building resources, taking into account the particular needs when it comes to critical and complex buildings. Figure V-B gives a general overview of the FUSE-IT approach for the BMS, focusing the Advanced and Optimization layer.

The Advanced Management and Optimization layer requires a precise set of data, from real-time consumption and generation data provided by the monitoring layer, to building users requirements and comfort needs, as well as critical zones and resources. In particular, historical data is used for knowledge discovery about building functioning and users needs, and to feed forecasting algorithms for the estimation of expected consumption needs and available generation.

Despite EU demand response encouragement[2] a lot of opportunities and challenges still remain, in particular for Europe and concerning Smart Building appliances[3]. The Smart BMS proposed by FUSE-IT will go beyond the resources usally considered (distributed generation, storage, consumption needs) by adding load flexibility as a resource in the mathematical formulation for the optimization problem. Hence, the multi-agent system optimizes the use of flexibility in the local area while assuring the BMS optimization as a whole.

In critical and complex buildings, load flexibility needs to be managed keeping critical processes, zones and equipment with full availability. FUSE-IT's optimization methodologies will face building criticality by dynamically attributing priorities to the resources. Specific building needs and time limits for demand response events participation will drive such priority definitions.

Building efficiency evaluation will be done according to cross-domain KPIs as defined in sec. II. The KPIs related to energy resources represent a relevant share of the overall building efficiency, and four domains costs are a common KPI.The evaluation of building efficiency under different environmental and operational contexts is a key issue for the machine learning approaches to perform smart decision making.

The combination of forecast, knowledge discovery, machine learning and multi-objective optimization will provide the needed inputs for the MAS management and control of building resources. Using MAS with these technologies brings advantages on: i) efficiency and scalability due the decentralized execution of algorithms the coordination being achieved via negotiation, ii) autonomy since each smart device performs its own schedule and iii) reliability under degradation conditions.

VI. Conclusion

This paper positioned the definition and exploitation of cross-domain KPIs as a major requirement for the next-generation of Building Management Systems to provide a global overview for the performance of critical sites. We have also demonstrated how the holistic view of the performance could benefit from the recent research advances on decision and optimization theory. Still, a lot of work remains in the peculiar definition of cross-domain KPIs. As we have seen in this paper this work supposes to take into account the specificity of critical sites. The design of the next-generation Building Management Systems also remains to be done and should involve standardization efforts in a context where closed system is the rule.

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