eSONIA Information Model development for supporting KPIs building

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Abstract

The present paper presents a part of the research developed in the scope of an European funded project named eSONIA, "Embedded service oriented monitoring, diagnostics and control: towards the asset-aware and self-recovery factory", funded by Artemis. The objective of the eSONIA project is to overcome the traditional monitoring activity by extending the ability to elaborate raw data and offer high value information exposed as web services at various enterprise levels. This allows to progressively avoid the use of large centralized processing systems to collect data.

The paper presents the description of a proposal for the Information Model to be used by the platform developed within the project. This model establishes a common background in order to structure information; it is used for generation and management of performance indicators at run-time.

Finally, the paper ends with an overview of the future integration of the Information Model into a larger model as part of an ongoing activity in the scope of the eSONIA project.

1 Introduction

Monitoring a production plant needs to collect information and evaluation parameters from the plant itself and its equipments. Many articles define Key Performance Indicators, in particular (Jovan & Zorzut, 2006) (Lohman, Fortuin, & Wouters, 2004) define KPIs as "a variable that quantitatively expresses the effectiveness or efficiency, or both, of a part or of a whole process, or system, against a given norm or target". The definition of KPIs in (Office of Public Management: Planning and Monitoring Your Program: First Steps in Program Evaluation) is referred as a more sophisticated one by (Jovan & Zorzut, 2006) which is: "A performance indicator defines the measurement of a piece of important and useful information about the performance of a program expressed as a percentage, index, rate or other comparison which is monitored at regular intervals and is compared to one or more criterion". (Parmenter, 2010) states that "KPIs represent a set of measures focusing on those aspects of organizational performance that are the most critical for the current and future success of the organization".

As stated by Peter Drucker: "You cannot manage something you cannot control and you cannot control something you cannot measure" (Smith & Mobley, 2008). The increasing competiveness in market nowadays has led to a demand for companies to manage their business more efficiently. There is a new requirement for flexible production, increased production efficiency, rapid response to customer demands, and high and uniform quality of products and services. An important solution for a successful production management is to design key performance indicators (KPIs) (Rakar, Zorzut, & Jovan, 2004), which are used to measure the effectiveness or efficiency of a system.

To this end, this paper deals with the definition of KPIs at different enterprise levels and with a special concern to KPIs that can be built with information coming from embedded system, installed at the shop-floor level. In particular smart wired and wireless sensors (e.g. STM, Atmel, TelosB) will be included in the architecture, to allow data processing at distributed level on the shop-floor. Information about energy absorption, vibrations, temperature are then translated into proper KPIs.

KPIs are a “bunch” of data that are easily interpretable if built in the right way. In order to properly manage the building of KPIs, it is important to structure an Information Model, to organize information and allow proper use of information to build KPIs.

The Information Model is a model that represents the reality of the world, therefore the concepts in the information model must reflect such reality: it must be close to both physical and logical objects in the real world and define their relationships.

In order to define the eSONIA Information Model, the project is going to follow the guide and recommendations described in (Natalya & McGuinness, 2001). The research idea for this paper is to apply an iterative approach, starting with a first description of the core information model parts and the terms/concepts that should be included. Then, the requirements from the eSONIA application domains will be also considered to refine the Information Model, in order to ensure that all the required concepts are collected in the eSONIA Information Model.

In section 2 the concepts related with KPIs are presented, with specific concern to the project approach. In section 3 the main elements constituting the Information Model are listed. Since this paper presents an ongoing research, section 4 shows the issues to be considered for the automotive manufacturing use case, developed by the eSONIA project. Section 5 introduces the future development that will lead to the completion of the Information Model; eventually, section 6 provides conclusions.

2 Key Performance Indicators

When dealing with information coming from the shop-floor, Key Performance Indicators can be estimated from two type of sources: directly from the embedded devices data or from the aggregation of these (and other) data. The former KPI method is referred as Embedded KPI (eKPI), according to the terminology used in the eSONIA project. With eKPI, the processing of the data is performed at device level (locations 1 and 2 in Figure 1). Therefore, this method reduces the complexity at higher levels.

The eKPIs are suitable for calculating well known KPIs which depend of couple of variables and do not require historic data. It is worth noticing that a change in KPI calculation triggers a change in the programming of the devices. Moreover, if several data from different devices are required, the computational resources of the embedded devices may be insufficient.

According to eSONIA project terminology, the later KPI calculation method is referred as Historical KPI (hKPI), where the data need to be aggregated at higher levels and correlated in order to provide information (locations 3, 4 and 5 in Figure 1).

The hKPIs are suitable for estimating well known KPIs and newly generated KPIs (especially the latter). The calculation of the KPI can be done at run-time, without need to interacting with the embedded devices. Therefore, this is a much more flexible mechanism than eKPI. Although, hKPI requires that the user (in the higher level) has knowledge of the data generation (in the lower level). Moreover, this consumes more resources in the higher enterprise layers (which could be also alleviated by the usage of cloud computing).

The use of eKPI and hKPID provides great flexibility and composition to generate new and complex KPIs.

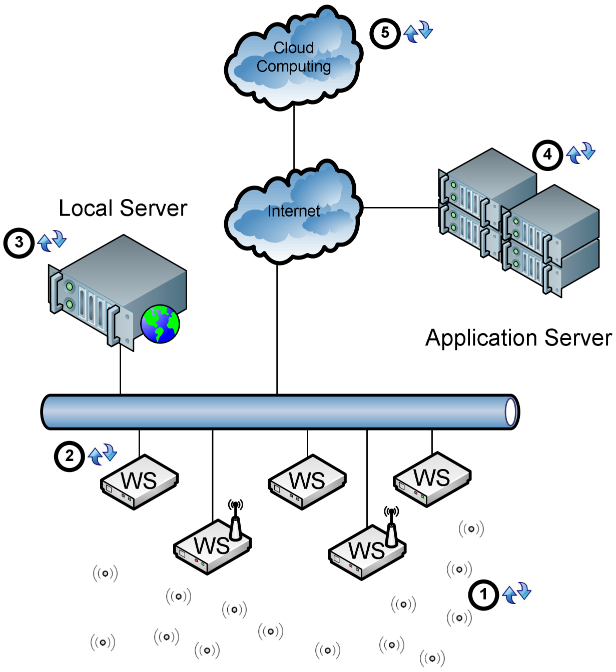

Figure 1: Estimation of Key Performance Indicators at different enterprise levels

It is quite clear that different (K)PIs serve different purposes, and that they depend on the domain they are supposed to evaluate. As such, the relevant (K)PI that must be considered in the eSONIA project have to be mentioned in a domain specific way, that is to say, in a use case dependent manner. To this concern, specific features of the Information Model are considered to be able to consider domain specific characteristics for the building of KPIs

3 Information model

This section aims at presenting the information model to support the building of KPIs. The information model is very important for the management of performance indicators, because it allows building the right indicators and providing the framework to structure the information.

The model outlines how data are stored in the database and their semantic, in order to further process the information to obtain the KPIs.

Data must be classified according to the type of information that is stored. Information generally comes from different sensors installed on machines, physical systems/subsystems, other information systems or fusion of different KPIs.

According to the architecture proposed by the eSONIA project, the information is managed by web-services and different web-services are used to cope with the above mentioned three sources of information.

Despite the source from which the information comes, the data almost always refers to physical systems, i.e. there should be always a univocal connection between the data recorded and a machine/subsystem. Even when information are derived from data fusion of different KPIs, the resulting indicator is related with something physically existing in the plant.

Thus, it is important to record in the information model: i) the source of the information (e.g. the web service that is providing the information), specifying also if the information comes from another indicator/or more than one indicators (this also allows to further check dependencies among the indicators); ii) the logical physical object to which the data is related.

3.1 Information about type of the machine

The identification of the type of machine from which the data come allows further analysis and provide useful information for the building of proper KPIs.

The information model should describe the different information that can be stored for different type of machine, accordingly to the industrial needs (considering the information needed to build the KPIs).

Furthermore this first kind of classification allows building proper KPIs according to the type of machine/subsystems that is considered.

The information model of eSONIA project is built based on an adaptation of the physical aspect description introduced by P-PSO ontology, this allows to describe machines in the plant, their attributes and so the KPIs of each one of them.

P-PSO (Politecnico di Milano – Production Systems Ontology) (Garetti, 2011) is based on a structured representation of the domain of manufacturing systems, which is supported by the object-oriented methodology, enabling the description of all the relevant aspects of a generic manufacturing system. This structure can be considered as a metamodel of the manufacturing systems domain, since it specifies the entities (building blocks) it is made of, their attributes and their relations, thus defining a standardised data format for their description. For what concern the Information Model here presented it is useful to refer to the part of P-PSO that describes the physical aspects of a production system (P-PSO is also composed by other parts, regarding the transformation and control aspects that are not considered in the current version of the Information Model). This part contains the physical (static) definition of the system including workers, production facilities (including tools, jigs and fixtures), material handling equipment, storages and other supplementary devices.

The eSONIA Information Model grounds on physical aspect layer, which suggests to describe the equipment in the plant by an object oriented view, so the two main classes are: subsystem and components.

The subsystem class denotes an aggregation of resources, which in their turn can be other subsystems, or else elementary resources, that are defined as components. The subsystem class can be used for managing different levels of detail of a manufacturing system, denoting a generic group of plant resources. The subsystem class has a fundamental role in P-PSO modelling as it allows creating customized building blocks that can be used everywhere in the object model.

Components are elementary resources of the physical aspect. In the P-PSO modelling assumption, the object component is a physical element of a manufacturing system that cannot be further decomposed. Specializations of the component class are the classes: processor, transporter, storage, operator, tool, fixture, unit load (see table 1 for the description of some of these classes). Each one of these objects can have attributes and so specific related KPIs.

Processors	Entities performing a manufacturing process function, i.e. transforming the material they operate on by using an energy source; types of processors are for example: machining centers, inspection devices, assembly machines, etc.
Transporters	Entities performing a transportation function, i.e. moving material between different points of the manufacturing process; types of transporter are for example like AGVs, conveyors, fork trucks, and other manual or automated transport machines, dedicated to the function of transferring and handling workpieces to various locations throughout the factory;
Storages	Entities performing a storage function, i.e. keeping material for later use into the manufacturing process; types of storage are for example buffers, automated storage and retrieval systems, dedicated to the storage (more or less temporary) of the workpieces.
Operators	Operators can directly perform activities (for instance of processing and transport), and also carry out support and supervision activities. Therefore the Operator class has special relationships with the transporters, storages and processors classes.

Table 1 – Description of classes of physical elements of a manufacturing system - Table derived from Garetti 2011

3.2 Information about time and metric

Signals are acquired from the sensors and from different web-services; then they must/can be elaborated, also allowing aggregation of information and data fusion to build KPIs from different indicators.

Some data can be then directly recorded into the database, while other data must be recorded after a certain elaboration, e.g. filtering, calculation of average value, integer, etc. in order to properly store the information. This means that some information is elaborated and then stored. Anyway the original information adopted, if also stored as KPI, has to be recorded in order to keep trace of the elaboration and clearly identify dependencies. Moreover, both real-time data and historical data can be processed.

To this end, some data can be recorded with a certain timestamp; they represent punctual data/measure such as the instantaneous temperature of a resistance installed on a machine. Other data can be stored with a timestamp to register when the information is transmitted and recorded, but the valuable information is the time frame when the data have been collected.

For instance, consider the measurement of the number of pieces produced by a machine (e.g. 5 pieces). It is important to know also the time frame when this information is recorded (e.g. 30 minutes), in order to allow then to calculate the rate of the machine (10 pieces/hour). This is valid both for discrete manufacturing and for continuous flowline systems. To perform operation like integration or evaluation of the mean one need the measure of the time-span, this explain the importance of the timeframe information.

To sum up, the information model must consider:

- Timestamp when the data is recorded
- Time frame of the information recorded

Indeed, the information about time frame can be also recorded by the difference of the two temporal events (start and end). If required, this can generate a second information (i.e. an indicator) which is generated with the information of the previous two.

Then data must also be clearly identifiable, so other fields to be considered in the information model are:

- Name of the information recorded (e.g. temperature)
- Metric of the information recorded (°C)
- Value (indicating if the value is an integer, text, number with decimals, etc.)

The following table shows all the entries for the data to be collected in the information model. An example has been added to clarify the concepts.

Variable	Explanation	Example
Name of the variable	Is the name associated to the indicator/KPI	Product delivered by the machine
Time-stamp	When data is acquired	03-06-2011, 15:37
Source (type of Source: Physical)	Identification number of the physical sensor from which the information comes or the information system from which the information is acquired	XY675
Source (type of Source: Web-service)	Identification of the Web Service providing the information. Web Services are identified by their End Point Reference	http://[2001::FE22A23]/OutputSensor
Source (type of Source: KPI used for the calculation)	In this field the KPIs that the Web Service adopts to prepare the variable stored in this row can be indicated and described, allowing identifying dependencies	“Kg of Material that flows from Machine ZX”, “Weight of each part”
KPI configuration	Textual description of derived/aggregated KPIs describing informally their algorithms (i.e. how a KPI will be computed from its dependencies by a particular web-service) to provide their initial	N.A. in the example

	specification	
Machine ID	Identification number of the machine where the sensor is installed when the measure is acquired	Machine ZX
Machine type	Identify the type of machine. This allows to consider the proper information to be stored as related to a specific type of machine. It is also useful for later create the proper KPIs (i.e. KPIs for Milling Machine)	Milling Machine
Value	This variable is one of the possible variables that are related to the machine. The information model should provide a list of them	7 *(Note: the information model should describe the type of variable stored (text, integer, etc.).*
Unit of measure	Specify the unit of measure of the previous field	Pieces
Point of reference for relative distance measure	Point of reference to calculate distance where the indicator would be	N.A. in the example

Table 2 – Variables to be considered into the Information Model (Table derived from Deliverable 4.3 eSONIA Project)

From the data recorded in the above table 2, for instance, the KPIs production rate can be derived:
7 kg in 10 minutes, equal to 42 kg/h as production rate of machine ZX at time 03-06-2011 15:37.

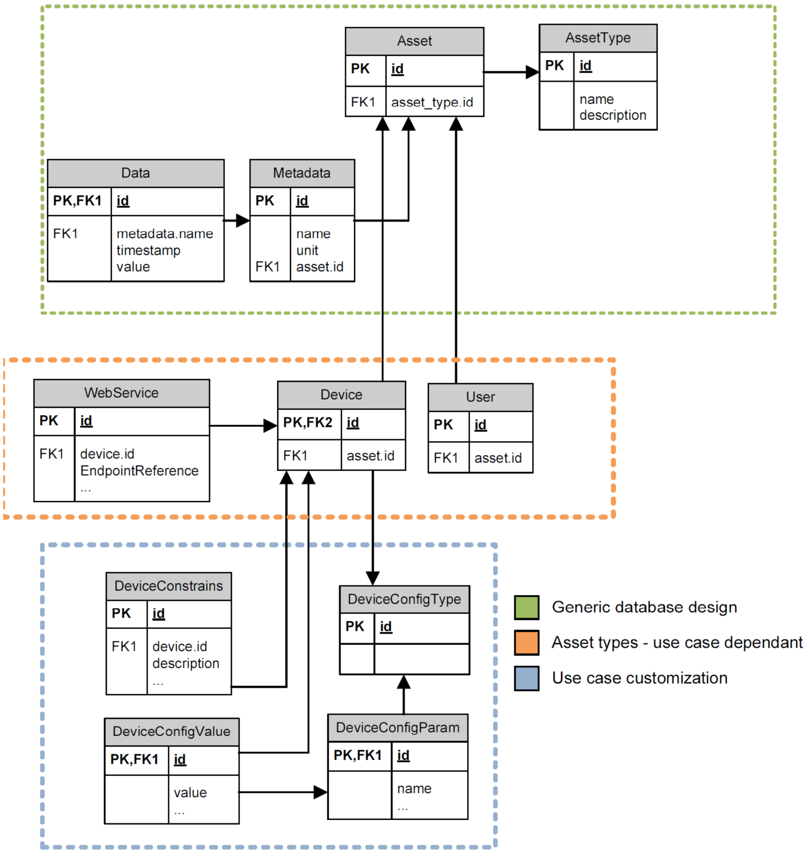

Fig. 2: Generic eSONIA Information Model (UML language) – D4.3 eSONIA project.

Figure 2 presents a conceptual schema (UML language) of the information model. In this conceptual model it is shown the generic part of the information model and the parts that would be customize according to the context of each use case, according to specific use case customizations due to the devices adopted.

The upper part of the model (circulated in green) of Fig. 2 represents the generic model which it is expanded by every scenario adapting this approach. This generic model represents the basic relationship between assets and data. The different use cases then instantiate their particular assets in the orange region. In the case of eSONIA, the common asset types are Web Services, devices (i.e. machines), and users. Finally, Fig. 2 presents a sample use case where the details of the machine information is provided (in blue, at the bottom). The model at this level is very depended on the granularity required to access the information in order to generate the desired Key Performance Indicators.

4 The eSONIA automotive manufacturing use case

One use case identified by this industrial partners of the eSONIA project is focused in the automotive manufacturing sector and carried out based on COMAU production systems.

In order to obtain a real enhancement of manufacturing control strategies, the systems are able to perform the monitoring of an increased number of signals from the field thanks to smart devises installed on the manufacturing system. This enables to perform smarter request to the plant management and to elaborate more efficient control strategies, thanks to the indicators that can be derived from the eSONIA platform.

At field level, the sensors are able (in this mentioned use case) to monitor e.g. the values of current and tension. The devices are able to correlate and elaborate immediately these data to generate useful information, that can also generate advise in case of a failure, carrying out a diagnostic activity, reducing time to repair.

The communication with the humans is provided in order to monitor and manage low level activities (single sensor condition, alarm and fault signals, etc). This low level interaction between user and devices connected to the local network is required to ensure real time control and safety issues.

The following table summarizes some information with the purpose to highlight the type of data that the information model should be able to store.

Sensor	**Item**	**Description**
Temperature and Humidity	Temperature Range Humidity Range	-10 ÷ 80 °C 0 ÷ 100 % Hr
	Temperature Resolution Humidity Resolution	0,5 °C 1% Hr
	Sampling Time	≤ 1 sample/30 s [0,05 Hz]
	Response Time	≤ 1 s
	Output Signal	CAN
	Supply	24V (max 100 mA)
	Data processing	Single value
	Energy Saving Options	Stand-by mode (with CAN message)
Voltage	Voltage Range	690 VΔ
	Voltage Resolution	1 V
	Sampling Time	1 kHz
	Response Time	≤ 1 ms
	Output Signal	CAN
	Supply	24V (max 100 mA)
	Data processing	True RMS, DC component, THD (TBE)
	Energy Saving Options	Stand-by mode (with CAN message)
Current	Current Range	80 A
	Current Resolution	1 A
	Sampling Time	1 kHz
	Response Time	≤ 1 ms
	Output Signal	CAN
	Supply	24V (max 100 mA)
	Data processing	True RMS, DC component, THD (TBE)

Sensor	**Item**	**Description**
	Energy Saving Options	Stand-by mode (with CAN message)
Air/H2O Flow and quantity	Input signal	pulses
	Sampling Time	≤ 1sample / 20 ms
	Response Time	≤ 1 ms
	Output Signal	CAN
	Supply	24V (max 100 mA)
	Data processing	Simple data (flow) Time integration (quantity)
	Energy Saving Options	Stand-by mode (with CAN message)
Process Temperature	Input signal	PT100/PT1000
	Sampling Time	≤ 1sample / 20 ms
	Response Time	≤ 1 ms
	Output Signal	CAN
	Supply	24V (max 100 mA)
	Data processing	Simple data
	Energy Saving Options	Stand-by mode (with CAN message)
Analog Signal	Voltage Range Current Range	0 ÷ 10 V 4 ÷ 20 mA
	Voltage Resolution Current Resolution	0,02 V 0,05 mA
	Sampling Time	1 kHz
	Response Time	≤ 1 s
	Output Signal	CAN
	Supply	24V (max 100 mA)
	Data processing	Single value
	Energy Saving Options	Stand-by mode (with CAN message)

Table 3 – Information to be collected and managed by the Information Model for the automotive sector use case (derived from D3.3 of eSONIA project)

Focusing on maintenance capabilities of the platform, abnormal behaviour can be detected before a fatal crash occurs, during its growing and this can be done according to the possibility to monitor the important maintenance KPIs. The followings are tables summarizing the Automotive Manufacturing indicators, namely performance indicators (PIs) and key performance indicators (KPIs) (collected in Deliverable D4.3 of eSONIA project).

	Name
PI	Instant power consumption
PI	Instant water consumption
PI	Instant air consumption
KPI	OEE
KPI	CO2 per car produced
KPI	Manufacturing cycle time
KPI	Power consumption per hour
KPI	Water consumption per hour
KPI	Air consumption per hour
KPI	Power consumption w/o production

Type	**Name**
KPI	Water consumption w/o production
KPI	Air consumption w/o production
KPI	Parts produced per hour
KPI	Max/Min/Avg CO2 per car produced
KPI	Total costs for each car
KPI	MTTR
KPI	MTTF
KPI	MTBF
KPI	Power consumption for A/C
KPI	Power consumption for A/C w/o production

Table 4 and 5 – KPIs to be considered for the Automotive manufacturing use case (Table derived from Deliverable 4.3 eSONIA Project)

5 Future development

In a dynamic environment, the context of the application changes over time, in terms of the entities available on the environment to be observed. These changes must be managed transparently or controlled by the end-user. The highest objective of eSONIA Information Model is to model the equipment and all its actors according to the context, so the next steps of the project will lead to define how the context information is modeled. Further development of eSONIA project will lead to integrate the above introduced Information Model in a wider model and cover all aspects in order to design a model able to adapt automatically to context execution. Moreover this will be also integrated into an ontological tool environment.

The project will follow several steps to define a context-aware model, in particular it will be determined the domain and the scope from the eSONIA use cases. Then, the core of the Information Model will be designed for five high-level parts (according to a preliminary analysis done by the eSONIA consortium) that compose the system: physical equipment, users, data, sensors and services. Later these parts will be refined with a top-down approach, to give more details to the description, and then formalized by the use of existing ontologies.

6 Conclusion

The eSONIA Information Model has been designed to help the monitoring of a production plant, in particular to keep trace of performance indicator from different machines on the whole plant. The importance of key performance indicators (KPIs) has been hightlighted at various enterprise levels and some different types of these indicators have been mentioned: eKPI (embedded key performance indicator) and hKPI (historical key performance indicator). A structured Information Model, as the one introduced in the third section, supports these indicators.

The suggested physical aspect description gave to eSONIA a tool to represent the available equipment and to trace the machines or subsystems, which KPIs come from. Moreover, details from a practical use case have been provided to support which are the starting points (data from the field) and which are the results expected (PIs and KPIs), supporting the need of the Information Model supporting the KPIs building.

Information about future integration of the Information Model into a larger model has been eventually provided, in order to highlight present and future research activities in the scope of the eSONIA project.

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