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EPES: Engineering System for Optimization of Product life-cycle through adapted eco-services

Mikel Sorli[a], Alberto Armijo[b,]*

[a, b]*Innovation Strategies Division, TECNALIA, Derio, E-48160, Spain*

Abstract

EPES system will consist of a set of interoperable ICT tools, which will enable the manufacturing and engineering companies enter into a continuous process of upgrading their products along their life cycle within the frame of the Virtual Factory and Product Service System concept, through a configurable and adaptable set of software services. The services will focus on improving the performance of products in operation taking into account different knowledge based aspects as reliability, availability, maintainability, costs, productivity, quality, energy efficiency, environmental impact, working environment, etc. In this regard, and having as a reference an industry driven Business Case focused on the windmill sector, the approach followed by EPES to generate and develop high added value services to support the windmill farms maintenance will be discussed. The capabilities resulting from the research will enable the capitalization on trustable global and local Sustainability Intelligence. Product engineering teams will be able to exploit this intelligence to adapt design, operation and disposal strategies through managed “eco-constraints” relevant to their market contexts.

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Keywords: Virtual Factory; Sustainability Intelligence; Optimization; Simulation; Eco-constraints

1. Introduction

Optimization of the life-cycle of existing industrial products is very much dependable on the possibilities of continuously updating them by incorporating edge technologies, replacing worn out pieces by new improved ones, even conceptually changing components of the product itself.

* Corresponding author. *E-mail address:* mikel.sorli@tecnalia.com, alberto.armijo@tecnalia.com

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New industrial products will surely benefit from the possibilities of incorporating incoming and more sustainable best available technologies. However, the highest impact will result in extending the operating life of existing products towards the "Long Life Eco-products" concept as described in Sorli et al. (2012) and Heilala et al. (2012). For instance, traditional maintenance systems just cared on replacing worn out parts without a knowledgeable analysis of the upgrading possibilities that may rise from the concepts of sustainable development. Hence, EPES eco engineering system (EPES Project 2011) goes, in fact, far beyond these traditional maintenance systems, incorporating knowledge (eco-constraints and objectives) coming from the environmental and social bottom lines, aimed at achieving a continuous improvement of product operation and end-of-life use so as to cover upcoming requirements related to several sustainability aspects, such as:

- Improvement of energy efficiency, environmental impact, waste management, etc. during the operating life of the product
- Enhancement of the useful life span of the product
- Improvement of environmental impact by disposal at the end of life; increasing re-use (re-manufacturing, overhauling, components transferring, etc.) and reducing waste
- Optimization of productivity (availability), reliability, maintainability
- Reduction of overall costs in operation
- Improvement of working environment: more friendly products, easier to use and maintain, and improved workers' health and safety conditions
- Collaborative Knowledge Management on the products by means of the Virtual Factory (Camarinha-Matos et al. 2008) by integration of actors: producer, customer and user, maintenance service, technology providers, experts and researchers, aiming at product design improvement by knowledge reuse

EPES will focus on the research and development of novel methods and tools for the conceptualization of an eco-process engineering system, which will constitute a comprehensive platform that will enable a dynamic composition of "eco-advice" services adaptable to the different products and operating conditions. This framework will leverage a sustainable life-cycle management of existing products in operation.

2. EPES European Project: Eco-Process Engineering System for composition of services to optimize product life cycle

Upon the above mentioned needs, EPES project (September 2011 – September 2014) was submitted and, following a successful evaluation, got funded by the European Commission under contract FP7-FoF-ICT-2011.7.3-285093. The project approach is to develop a set of software components, as shown in Fig. 1, which will constitute an Eco Process Engineering System enabling the industrial companies, including SMEs, to generate innovative dynamic life-cycle services oriented to follow-up a continuous improvement of product operation and end-of-life use.

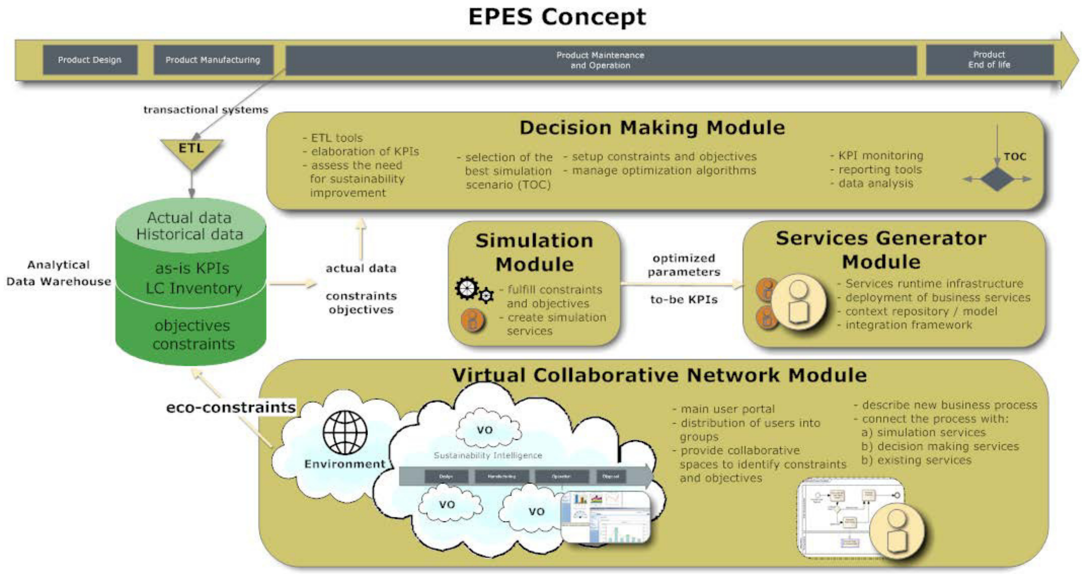

Fig. 1. EPES Concept

2.1. Project description

The overall idea of the project is to develop a set of ICT tools, which will enable the manufacturing companies to continuously upgrade their products along their life cycle in close collaboration with key actors as users, maintenance experts, technology providers, experts and researchers, etc. The ICT tools will be surrounded by a methodology that will provide guidelines for building up the Virtual Factory and will allow the migration to the new working paradigm. The process will use knowledge and expertise from different sources that will be captured, stored and reused by means of an EEKB (Eco-process Engineering Knowledge Database). The concept of Life Cycle Thinking (LCT) will be applied, which seeks to identify possible improvements to goods and services in the form of lower environmental impacts and reduced use of resources across all life cycle stages. This begins with raw material extraction and conversion, then manufacturing and distribution, through to use and/or consumption. It ends with re-use, recycling of materials, energy recovery and ultimate disposal. The key aim of Life Cycle Thinking is to avoid burden shifting. This means minimizing impacts at one stage of the life cycle or in a particular impact category, while helping to avoid impacts during other life-cycle phases of a product.

The key software components of the EPES solution include (see Fig. 1):

- Virtual Collaborative Network (VCN): to allow the tracking of business optimization opportunities and the development of process optimizations through a networking infrastructure. It also provides collaborative web content and document content management capabilities complemented with workflow execution capabilities
- Service Generator Module (SGM): to allow configuring EPES Services, deploying them, to provide a cockpit/portal to access EPES solution, and capabilities to leverage the EPES Services from a VCN workflow
- Decision Making Module (DMM): to allow decision-makers to optimize and to analyze business processes through dedicated tools
- Simulation Module (SM): to allow execution of external simulations and provision of parameters for calculation of sustainability indicators

On the other hand, the EPES methodology will provide a comprehensive approach on how to adapt and use the EPES solution. In order to enable applying the solution in a new situation, the methodology will include such aspects as business process model (mapping it and making it explicit), collection of Sustainability Intelligence (SI) sources, classification and structuring of the SI information, etc. The overall way of working and expected functionalities of the SW modules are also to be included in the methodology.

2.2. Project approach

EPES project follows an end-user driven approach, through the specification of three Business Cases (BC) or demonstrators, which will be used to implement and validate the results of the project. Thus, the three EPES industrial partners (TAMOIN, nkt and EADS) supported by the RTDs identified for which key processes, within the product life cycle, they intend to explore the developed software components so as to optimize them towards sustainability. The project is being applied to the following sectors:

- Wind mill engineering (BC1): Generate and develop high value added services to the windmill farms maintenance
- Energy (BC2): Supporting services easily adaptable to customer specific needs, which facilitate the analysis and maintenance of cable systems with respect to a secure use of increasing cable capacity, due to the increasing share of renewable energy in the European Union
- Aeronautics (BC3): The project will identify eco-constraints relevant to the manufacturing systems assessment capability at the right point in time in aeronautics sector

2.3. Objectives

The objective of this paper is to introduce the application scenarios that were envisaged for the Windmill engineering Business Case (BC1). Based on these scenarios and the ones associated to the rest of Business Cases, some generic requirements were elicited, which eventually led to the specification of the software components of the EPES Solution. The aim of these components is to facilitate the creation of generic and configurable software services that can be customized and combined with Business Case specific tools/services to build EPES Services that support the introduced application scenarios.

3. EPES BC1. Engineering maintenance services for optimizing maintenance and increasing availability of wind turbines (BC1)

3.1. TAMOIN Current situation

This section presents the Spanish Business Case that is being developed within EPES project. This Business Case is led by the wind farm division of TAMOIN Energias Renovables, which is an industrial company specialized in rendering services for the installation and maintenance of wind farms located in Spain.

TAMOIN has several regional offices, drawing a diagonal from the northwest to the southeast of Spain. Each one is responsible for several wind farms, depending on the number of wind turbines and the distances between the wind farms. Each regional office prepares and manages a detailed annual planning and short term (weekly) planning, which usually spans 7 days.

The short term scheduling is normally updated every week and the planned preventive maintenance tasks are executed according to the schedule. When the execution of a task takes longer than planned, the remaining tasks of the same team are shifter later without changing the order. However, when an alarm is triggered at a wind turbine that requires an urgent corrective action, the area supervisor in the regional office tries to contact nearby maintenance teams, permanently assigned to a wind farm, by mobile phone and orders them to fix the failure as soon as possible.

TAMOIN maintenance tasks can include the replacing of worn out components, replacing of broken down components, inspection and monitoring, cleaning, retrofitting and overhauling, technical audits, etc. TAMOIN maintenance programs are focused on:

- Predictive Maintenance (condition based monitoring), triggered by a prognosed failure
- Preventive Maintenance, which can be foreseen and planned before the component needs to be replaced due to failure or underperformance. These activities are scheduled (short term scheduling) with an horizon of seven days
- Major Corrective Maintenance, released for scheduling upon the localization of a failure, requiring auxiliary means
- Minor Corrective Maintenance, released for immediate scheduling upon the localization of a failure, requiring only spare parts as replacing components
- Retrofits and Overhauling, released by high level decisions

Maintenance tasks are executed by technicians, organized into teams of two people, stable within a shift. These teams are dispatched to wind farms based on the maintenance schedule (short term). Travelling by car from one wind farm to another takes a given amount of travel time. A particular team can execute only one task at a time and must be completed before moving to the location of the next task. Multiple teams are allowed to execute different tasks on the same turbine, unless simultaneous tasks are incompatible. All the maintenance teams are able to execute the majority of the maintenance works. Only a few complicated tasks might require the specialists or more than one team of technicians.

Each maintenance task requires a set of spare parts (e.g. bearings) and consumables (e.g. oil, grease) for each execution. The common parts are stored in the wind farm warehouse and the maintenance teams' cars, whereas seldom needed and expensive parts must be ordered from a central warehouse or a supplier. In this case, the area supervisor is in charge of the expected material arrival time, and schedules the maintenance task when all the parts are expected to be available. Some tasks may require special equipment (cranes or trucks), which must be hired from service suppliers.

A highly domain specific constraint of the scheduling process is the influence of the weather conditions, such as strong wind speeds, temperatures or precipitation. The proper conditions for carrying out works depend on the task type and the local safety regulations. A different effect of weather conditions on maintenance is that the production of the turbine depends on the wind speed. This implies that when a turbine must be stopped for maintenance, it is worth stopping it at the time of calm winds in order to minimize production loss.

The maintenance activities described above are managed through a Computerized Maintenance Management System (CMMS), which provides facilities for codifying, on the one hand, human resources' data referring to capacities and availability and, on the other hand, the availability of material resources. This CMMS allows TAMOIN to register the planned and completed maintenance activities of the wind turbines, the associated maintenance type, duration and involved resources (spare parts, consumables, auxiliary means and personnel).

However, technical data regarding turbine working parameters for each of the wind turbines and associated main components are commonly saved in other storage systems, which are independent from the CMMS. In this regard, and to obtain a comprehensive view of the whole process, the information coming from the turbines should be systematically gathered and integrated with the information from the CMMS in order to prepare the data for its exploitation and analysis, aiming at taking sound decisions regarding i.e. how to select and organize the maintenance tasks mix to minimize costs or optimize other metrics. Currently in TAMOIN, this data integration process is rather time consuming and inefficient, since some of the enterprise resources are constantly used for the centralization of data. These resources should be, instead, involved in the optimization of maintenance operations in the attempt to reduce the maintenance average time or forecast components failures in a shorter time.

3.2. TAMOIN Business Case scenarios

A regional office located in the northwest of Spain was selected for the development of this Business Case, comprising three wind farms with an average of 60 wind turbines per wind farm. Seven maintenance teams are in charge of the maintenance operations in the selected regional office. In order to extend current maintenance systems with the support of EPES infrastructure, two scenarios were developed:

- Optimization of the production organization (in maintenance) to achieve maximum wind turbines availability at minimum maintenance costs
- Elaboration of business indicators to measure, track and support the decision making process, aiming at optimizing the performance of the maintenance activities

The first scenario comprises an accurate maintenance scheduling, which is considered a complex problem where regional office managers must consider different aspects, such as human resources capabilities, experience and background, availability of expensive hired services (auxiliary means) and spare parts, as well as different interrelations of the maintenance tasks. In addition, the area supervisor (regional office level) should quickly adapt to variable situations that might modify the initial scheduling, such as changing weather conditions or newly detected severe failures that require the urgent use of already assigned resources. Finding an optimal maintenance schedule is a tough problem that requires decision support services from sophisticated scheduling systems as presented in András Kovács et al. (2011).

The second scenario focuses, on the one hand, on a system for capturing environmental eco-constraints and objectives derived from local regulations, regional regulations and sector recommendations, aiming at the identification and development of business key performance indicators (KPI) involving social and environmental measures. On the other hand, the system will also allow the extraction, transformation and loading of human, material and technical data into a data warehouse, targeting at the definition and elaboration of traditional key performance indicators involving profit and performance measures. The monitoring of these indicators will support the decision making process to achieve an optimal management of TAMOIN maintenance process.

Consequently, the overall objective of this Business Case is to improve the maintenance scheduling capabilities of TAMOIN by the provision of a scheduling system based on mathematical models aimed to achieve the goals/objectives or fulfill the constraints identified in the second scenario. In this regard, the goals by which the scheduling system can be tuned may involve the optimization of the total energy produced by the wind turbines, the minimization of the maintenance costs or a combination of both. On the other hand, the constraints that may restrict the scheduling involve, for instance, the resources availability, the tasks compatibility or the weather conditions.

Summarizing, the optimized scheduling capability along with the goals and constraints discovery and metrics tracking system will be enhanced with service oriented capabilities and offered as an EPES Service in order to provide collaborative, traceable and trustable decision support to TAMOIN.

4. EPES project innovation

EPES project is developing an ICT tool, supported by a RTD and Industrial methodology, for the assessment and optimization of technical systems from a product life-cycle point-of-view. EPES system will include Web 2.0 features for collaborative design, an extended enterprise knowledge repository, business process modeling tools and a simulation and decision-making platform with the ultimate objective of integrating a set of readily available tools into a modular and extendable system that facilitates the use, reuse, storage, analysis and sharing of knowledge within the Virtual Factory. Planned industrial demonstrations, derived from the above explained Business Cases, cover different stages of the technical product life-cycles, such as product and production system conceptual design stage, as well as at the operational and service stage.

As such, EPES project does not aim to develop any of the present technologies alone to further levels, but, instead, to innovatively combine them for achieving novelty functionality and more comprehensive interaction. As for including the simulation and optimization into the mix, the target for EPES project optimization is moving from large static, spread sheet models to more flexible dynamic, collaborative and integrated modeling. The same trend of moving from static isolated systems to more flexible loosely coupled system is largely present in the whole EPES concept. Thus, instead of having desktop applications and "engineering islands of analysis", EPES aims to fulfill integration of assessment methods and provide them as a service for non-simulation experts (but simulation models will remain domain specific).

Another substantial value EPES system aims to deliver is to bring environmental and social KPIs available to decision makers in addition to traditional economic KPIs. Traditionally, sustainability related factors have required specific LCA tools, and couldn't be coupled to VCN or simulation functionalities. In this regard, EPES system will augment the simulation and optimization models with Sustainability Intelligence with the purpose of taking into account these factors. As a general rule, Business Intelligence domain has been using for years traditional KPIs so as to assess the current business performance status and to prescribe future action lines. However, the increasing importance of sustainability and Corporate Social Responsibility (CSR) should also be assessed. Hence, managers should take into account not only increased sales and profits and/or decreased costs, but also sustainable development of the business itself and of the surrounding context. Sustainability Intelligence is the augmentation of Business Intelligence concepts with sustainable development concepts, where the traditional economic-financial bottom line is coupled with environmental and social bottom lines. Sustainability Intelligence Triple Bottom Line (TBL) system allows users, who may not be familiar with all the metrics and concepts of sustainable development, to make strategic sound decisions based on systematic data gathering, monitoring, analysis and distribution.

5. Conclusions

TAMOIN participation in EPES project as a Business Case provider and demonstrator is focused on developing high added value engineering maintenance services through the collaboration with RTDs and the other industrial BCs. The main objective is expected to be achieved by improving the data capture and knowledge management through the EPES eco-process engineering system, which will extend the functionalities of TAMOIN current maintenance software with new designed life-cycle services, comprising a service for the development and monitoring of business indicators for supporting continuous improvement activities and a service for planning and programming maintenance activities, which takes into account the optimal time frame for the maintenance of each component according to the failure probability of each of them as this probability increases throughout the life-cycle of the component.

These services will help the company to overcome present software limitations and will be configured and composed to optimize the company Wind Farm Maintenance Engineering services, offering to the customers a wider range of high added value services covering areas such as technical support, spare parts management, operation efficiency improvement, quality, environment and health & safety.

TAMOIN objective is to extend current maintenance systems through data capture and knowledge management techniques application via Sustainability Intelligence concepts. The final EPES solution is expected to allow TAMOIN to achieve an important leap forward increasing the ratio of wind farms served, improving the maintenance efficiency (reducing maintenance average times), improving procedures based on the analysis of previous maintenance records (via feedback to maintenance engineering staff) and forecasting the maintenance procedures needed to efficiently maintain the wind turbines that incorporate new technologies (new generation of wind turbines), which would reduce the maintenance time.

This solution is also expected to allow TAMOIN to expand to other countries and enter into new markets and cover other aspects of the life-cycle management such as disposal and design improvement, achieving efficient and sustainable life-cycle management of the wind turbine through a continuous improvement process.

EPES is one of the first attempts to provide a holistic methodology and tools to directly link Eco-driven engineering with generation of collaborative services around manufacturing products. The following aspects may be emphasized as novelty keys in the project:

- Dynamic definition of Eco-driven engineering processes within collaborative networks from a business perspective

- Capitalisation of trustable global and local Sustainability Intelligence based on holistic acquisition of relevant eco-constraints and objectives along the lifecycle
- Augmentation of simulation and optimization models with Sustainability Intelligence to assess the sustainability of optimized processes
- Scaling-up of augmented simulation and optimization capabilities from a desktop confined approach into enterprise-wide EPES Services to enable non-expert industrial practitioners to run optimization scenarios anywhere in the enterprise, leveraging collaborative and intelligent decision making, and to advise on the configuration of what-if scenarios
- Added value eco-driven services for the maintenance of manufactured products that are designed under the point of view of the overall life cycle
- Context Awareness Approach with Cloud Functionalities

Furthermore, the fact of working within distributed ICT platforms to manage intelligence would cause overall cost reduction in the Virtual Factory along the value chain because of sharing same needs or at least similar ones. This aspect is quite relevant for SMEs, which are represented in most of these value chain structures. In addition, the effect of sharing information, and having the feedback on it, could push more than one company to extend the relationships among them to other aspects as design collaboration, commercial complementary and so on.

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