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Eco Process Engineering System for highly customized industrial products, processes and services

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Abstract

The paper presents a new approach for evaluating the performance of engineered products based on the whole life-cycle, so that product engineering teams can exploit this information to adapt the design, operation, maintenance and disposal strategies of products and processes. By providing novel ICT solutions, which improve the performance of highly customized industrial products, processes and services (PPS) during their life, in cases, in which no standard, off-the-shelf solutions can be applied, continuously optimization can be achieved. Processes and services for products as well as maintenance require ICT solutions able to capture and process information from various actors and different operational phases with the objective of enhancing efficiency and improving sustainability performance, taking into account contextual information of the connected systems and operators. The approach along with the newly developed ICT-tools are assessed in the decision-making processes in three companies from different sectors (wind farm maintenance, cable production and aeronautics), which represent typical examples of companies in need for such highly reconfigurable services to continuously optimize product performance and service delivery.

1. Introduction

The optimization of industrial products' life cycle is a process of continuous update by incorporating cutting edge technologies, replacing worn out pieces by new improved ones, and conceptually changing components of the product itself. While new products benefit automatically from cutting edge technologies, the highest impact is achieved by upgrading existing products in operation, leading to the "long life eco-products" concept. The proposed approach uses several state-of-the-art technologies to enable evaluating the performance of engineered products based on the whole life-cycle, so that process/product engineering teams can exploit this information to adapt the design as well as operation of products. One of the key assumptions of this approach is that combining simulation, decision making and collaborative networks can be used to allow industries to evaluate the performance of engineered products considering anywhere along the product's life-cycle; by monitoring the development life-cycle and the product. The services supporting the life cycle can be configured in order to have faster update iterations. The approach has been applied within industrial settings, where the proposed approach is used to support more flexible and timely reconfiguration of product life cycle services [1]. Figure 1 below presents the general concept of the architecture in which the proposed approach has been implemented:

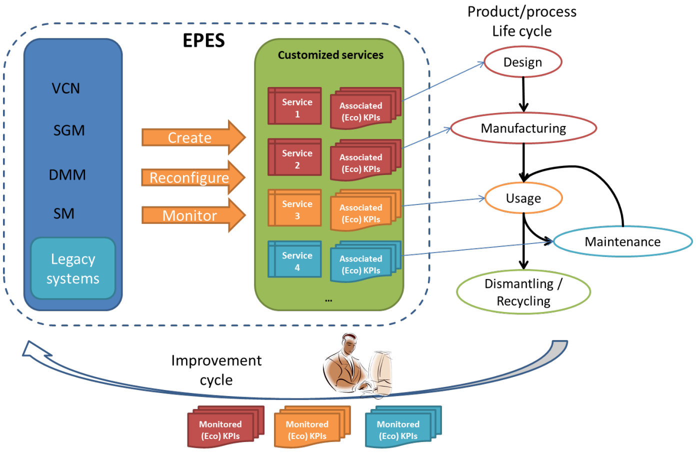

Figure 1: Proposed Concept

The Services Generator Module (SGM) is used for reconfiguring life-cycle services. A Simulation Module (SM) and a Decision Making Module (DMM) are supporting services, which can be used (potentially in conjunction with the Service Generator) for adjusting the parameters of life-cycle services. The Virtual Collaborative Network (VCN) supports the collaborative aspects, such as collaborative definition of KPIs.

The paper is structured as follows: Section 1 provides a brief overview of the key proposed concept. Section 2 presents a brief overview on the state of the art, while Section 3 explains in more detail the proposed architecture. Section 4 addresses the application of the proposed approach in three specific industrial settings, showing the current situation, the targeted objectives, and the way the solution is applied for achieving these objectives. Section 5 presents the conclusions and future work.

2. Related Work

The objective of the presented approach is to develop a novel eco process engineering system based on four core software modules, which can be combined into a comprehensive platform enabling a dynamic composition of services that are adaptable to the different products and operating conditions.

This novel service oriented framework allows industries to evaluate the performance of engineered products considering their whole life cycle rather than only early stages such as design and manufacturing (see Figure 1). The capabilities resulting from the research will enable the capitalization on trustable global and local sustainability intelligence. Product engineering teams can exploit this intelligence to adapt design, operation and disposal strategies through managed “eco-constraints” relevant to their market contexts. This allows for faster and more flexible decision making along the product life cycle: by analysing the context in which previous decisions have been taken, future decision-making can be improved [1].

Key research topics related to the proposed concept are the following, which are briefly characterized in the following sections.

2.1. Collaborative Networks

A definition of the network concept generally refers to a structure of interconnected elements, these elements can be people or things and the connections represent relationships between the elements. When network elements are people we are talking about social networks. Social networks are represented as a structure or an interlocking system of social ties among actors, individuals or organizations and in general these networks are initiated and maintained by people.

In the professional field, people belong to organizations or institutions and in this field networks are also defined. An inter-institutional network is understood to be a specific cooperation between several organizations designed to cover a longer period of time for the attainment of jointly stipulated objectives and added value for the individual participants [2].

Some of the main characteristics that define a network of organizations/institutions refer to common intentions among participants and they are oriented to individuals or groups of people. The main focus of the network is in sharing information as a tool of benefit to all members. Networks of people in general and institutions in particular are made up of one or more objectives or purposes, such as “Exchange of information/knowledge”, “Communication between members” and/or “Find experts”. While cooperation refers to the working ties of individual organizations, network refers to the huge number of cooperating partners. However, differentiating between the terms cooperation and network is not always applied with sufficient distinction, they are occasionally viewed as interchangeable, and the terms used synonymously.

The main concepts involved in collaboration and the main differences between all of them are the following ones: Networking, Coordinated Networking, Cooperation and Collaboration [3].

Collaborative networks appear in a diversity of forms and show a variety of behavioral patterns. Different collaboration forms can be identified according both structure and duration. In terms of structure, three collaborative network topologies seem to appear frequently in literature: Chain, star and general network topology [3].

2.2. SOA

A Service Oriented Architecture (SOA) is a logical way of structuring a software system into a set of loosely coupled components whose interfaces can be described, published, discovered and invoked over a network. These components are deployed as services with standardized interfaces, independent of any specific platform or implementation technology, and that carry out together a high-level function or business process (e.g., placing an order, making a credit approval) [4].
SOA is a relatively new term, but the term ‘service’ relating to software services has been around since the 90s, when it was used in Tuxedo to describe ‘services’ and ‘service processes’ [5]. Sun described SOA more meticulously in the late 90s to describe Jini, a lightweight environment for dynamically discovering and using services on a network, allowing ‘network plug and play’ for devices [6]. In computing, the term service has been used in different ways. Service oriented computing (SOC), Service oriented architecture (SOA), Web services (WS) are the most recent derivative terms. Services are independent, self-describing modules of code, discoverable resources that execute repeatable tasks and which are described by an externalized service specification [7].
Services are the core building block of SOA. There are some variations in SOA definition in terms of context, level of abstraction and wording; however the common and core indication of SOA is that, this is a paradigm for developing system flexibility. SOA is the driver of system’s flexibility in terms of autonomous integration between different levels, ensuring interoperability through standard based interface independent of implementation technologies, loose coupling to minimize dependencies leading to system’s scalability.
SOA implementation in industrial domain should be flexible and agile enough to facilitate a holistic integration at all level. Emerging web service standards for SOA implementation, for integration from device level to enterprise application level, manufacturing services orchestration and choreography for instance, incorporating intelligence even in the smaller devices through high performance microprocessors Lastra [8] has opened a new era for future knowledge based, and semantic web service enabled manufacturing capabilities.

2.3. Simulation

“Simulation is the imitation of the operation of the real-world process or system over time. Simulation involves the generation of an artificial history of the system and the observation of that artificial history is draw inferences concerning the operating characteristics of the real system that is represented." [9]. There are many ways to classify models. In dynamic system one-way to classify is: symbolic models, analytic models and simulation models [10]. Modeling and simulation are efficient tools for continuous improvements. Simulation as service is not yet a common practice; first commercial tools are at the market as shown here. Sustainability aspect and data can be integrated to the simulation analysis.

Web-based simulation is one relatively new concept that has evolved in the new web era. The appearance of the network-oriented programming language, e.g. Java and of distributed object technologies has had major effects on the state of simulation practice. These technologies have the potential to significantly alter the way we think of, develop, and apply simulation as a problem solving technique and a decision support tool. Three approaches for web-based simulation has been identified in the literature already in 1998 [11]: Server-hosted simulation, Client-side simulation and Hybrid client/server.

Until recently, the technologies used in Modeling & Simulation (M&S) have remained stubbornly non-Web-based. Now most major M&S tools, or Commercial-off-the-shelf (COTS) Simulation Packages, such as AnyLogic and Simul8, have web-based aspects. However, these have aspects more commonly associated with Groupware and certainly do not seek to take advantage of model/component discovery, composition, interoperability and reuse. [12].

Integration of sustainability and environmental aspects to simulations is one of the on-going development efforts in many research institutes. The development in the SIMTER project (2007-2009) was made using Visual Components 3DCreate software[1] and EU LCA platform database. Other similar efforts based on use of commercial software e.g. Anylogic, Arena, Automod etc. exist. NIST (National Institute of Standards and Technology) has used also system dynamics for sustainability modeling [13].

Life cycle simulation technique simulates circulation of products in the markets over the entire lifetime of products with a discrete event simulation technique. Sensitivity in environmental impacts of a product life cycle on different life cycle strategies is measured by integrating LCA inventory data (as unit input/output performance of sub-process) into life cycle simulation technique [14].

2.4. Decision Making

Problems with multiple objectives (or goals) and constraints are typical of many engineering fields. In most cases, the objectives are in conflict between themselves, precluding the applicability of classical optimization methods. This kind of problems is generally known as Multiple Criteria Decision Making (MCDM), where problems and are generally solved through a so-called optimization

[1] DES, http://www.visualcomponents.com/

procedure. The process of simultaneously optimizing two or more conflicting objectives subject to certain constrains is usually known as Multi Objective Optimization (MOO).
The main difficulty for Multi Objective Optimization methods lies in the handling of conflicts between the various objectives. The algorithm has to find and compare feasible solutions in terms of multiple objectives, while at the same time, verify the satisfaction of constraints that restrict some properties of the system to lie between pre-specified limits. Clearly, widely used single objective optimization methods are not applicable, due to the contradiction and possible incommensurability of the objective functions, which makes not possible to find a single solution that would be optimal for all objectives simultaneously.

2.5. Sustainability Indicators

In industry today sustainability measures are common. Ideally measures can be a guide to where you are, where you are heading and how far you are from the ultimate vision. There are parameters (figures you measure), indicators (figures that indicate something) or index (several indicators combined into one). They can be used for benchmarking, decision making, measuring or guiding to improvement on the operational level or enabling companies to identify more innovative solutions to sustainability challenges [15].
Feng & Joung [16] describes a multitude of various measurement initiatives for measuring sustainability metrics. Previous research and current developments lifted are for example [16]: Global Report Initiative, Dow Jones Sustainability Index, Environmental Sustainability Indicators, Environment Performance Indicators, United Nations Committee on Sustainable Development Indicators, OECD Core indicators, Ford Product Sustainability Index, GM Metrics for Sustainable Manufacturing, ISO 14031 environmental performance evaluation, Walmart Sustainability Product Index and Environmental Indicators for European Union.
Four fundamental principles form a framework for sustainability upon which sustainability indicators should be built [17]:

- Substances from the earth's crust cannot systematically increase in the biosphere.
- Substances produced by society cannot systematically increase in the biosphere.
- The physical basis for the productivity and diversity of nature must not be systematically deteriorated.
- There must be fair and efficient use of resources to meet human needs.

In addition, there are other important properties that indicators should fulfill. For instance, many agree on six important properties of good indicators or measures [16]:

- Relevant: Indicator must show useful meaning on the manufacturing processes under evaluation.
- Measurable: Indicator must be capable of being measured quantitatively or qualitatively in multi-dimensional perspectives, e.g., economic, social, environmental, technical, etc.
- Understandable: Indicator should be easy to understand by the community, especially, for those who are not experts.
- Reliable/Usable: Information provided by indicator should be trusted and useful. Reliable measurement is necessary.
- Data accessible: Indicator has to be based on accessible data. The information needs to be available or can be gathered when needed.
- Flexible: An indicator must be compatible with open standard expressions, such as ontology base and XML documents.

3. Proposed Solution

The proposed work addresses a generic solution for supporting optimizing process execution by enabling dynamic composition of services adaptable to the different products and operating conditions. In order to support this, the EPES solution will enables continuous improvement of products in operation along the life cycle of the products and for improving future product designs.

3.1. Architecture

The overall EPES reference architecture is illustrated in Figure 2 below and is built upon the following core services:
Virtual Collaborative Network (VCN): The VCN main functionality is to provide a main point of access for non-expert end-users through user interfaces, including capabilities for supporting the aggregated GUIs provided by the Service Generator. It provides the technical infrastructure for the distribution of users into groups; content management and sharing mechanisms; workflow engine for contents production, consumption and transformation. In addition, the VCN provides a Knowledge Base, containing actual data, historical data, identified constraints and objectives from collaborative networks, KPIs and Life-Cycle Inventory data.
Service Generator (SG): The Service Generator's main functionality is creating, updating, and deploying configurations for application-specific services. It interacts with the Simulation Module and the Decision Making Module to compute parameters for updated configurations. The SG can also store / retrieve configurations in/from the Virtual Collaborative Network. Finally, the SG allows identification of contextual information about EPES solution operators as well as connected legacy systems.

Simulation Module (SM): The simulation module of the presented platform provides a capability for running numerical analyses related to the life-cycle assessment process. It provides simulation services through an abstract service interface that allows higher-level components of the platform to use simulation as an interchangeable service, according to the principles of the SOA design paradigm. It allows the other modules to present configuration options and numerical parameters of simulation modules without any prior knowledge of the internal structure of the model.

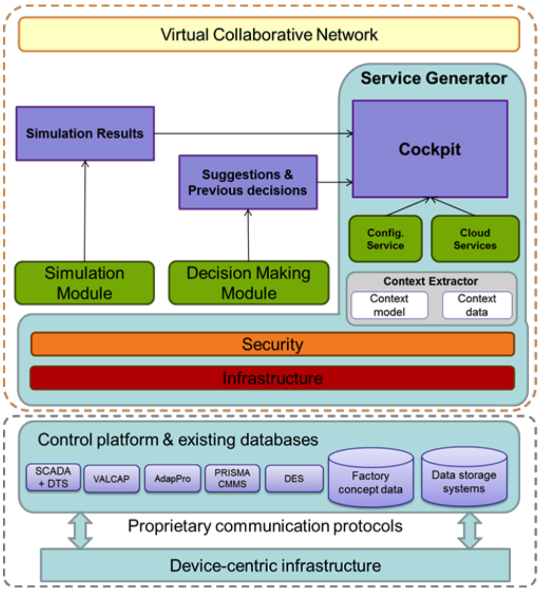

Figure 2: Proposed Architecture

Decision Making Module (DMM): DMM is an interactive system intended to help decision-makers to use data and models to identify and solve problems and to make decisions. On the one hand, there will be some Traditional indicators for measuring the overall factory performance, but on the other hand, there will be new KPIs established and defined in the DMM. These KPIs will be traced to the measured constraints, and the DMM will show, in each BC, where the constraints are, and how to measure the performance of the organization, in order to take the best decision in a range of values proposed by the SM taking into account the localized constraint. The KPIs taken into consideration will mostly reflect eco constraints. Inputs from the SM will support the decision process, by simulating the potential evolution of relevant KPIs and allowing thus taking informed decisions. The Data Analysis will be based on the well-known Open Source Pentaho Suite, which includes Business Intelligence products providing data integration, OLAP services, reporting, dashboard and data mining.

3.2. Application

The presented approach is being applied in three industrial business cases, to validate the proposed decision making solution within different application domains:

- **BC1:** Engineering maintenance services for optimizing maintenance and increasing availability of wind turbines. The decision processes involved here deal with the best maintenance route to be taken for optimal maintenance of multiple wind turbines.
- **BC2:** Power grid control systems for improved identification of improved monitoring of grid load and safety limits. Decision support methods are supporting the user in detecting trends in the grid load, ensuring thus that good load balancing decisions will be taken.
- **BC3:** Support for optimized design and manufacturing of aircraft wings. Here, the decision support system addresses the optimal layout of manufacturing facilities in the design phase.

Table 1 lists the identified main specific technical aspects of the three business cases, which are addressed by the generic proposed solution.

Table 1: BC-specific technical aspects addressed by the proposed solution

BC	Main Area of Interest	Technical issues to be addressed
BC1	Services for optimizing maintenance and increasing availability of wind turbines	Monitor parameters of wind turbines to detect preventive maintenance needs
BC2	**Power grid c**ontrol systems for improved identification of maintenance needs and monitoring of grid load and safety limits	Monitoring of cable temperatures and grid load to support decision making of load balancing
BC3	Support for optimized design and manufacturing of aircraft wings	Use simulations to estimate production rate, energy consumption, emissions, hazardous material waste

Each BC also deals with specific KPIs. These have been abstracted into generic KPIs that support the generic platform. Table 2 below shows the mapping between these generic and BC-specific KPIs.

Table 2. Generic KPIs abstracted from BC-specific KPIs

Generic KPI	BC1 specific KPI	BC2 specific KPI	BC3 specific KPI
CO2 Emission	Reduction of CO2 emissions due to the increment of availability Reduction of CO2 emissions due to logistics and personnel	CO2 emissions reduced by targeted hotspot maintenance	CO2 emission calculation based on energy usage

	movement optimization		
Energy waste	Energy waste due to low technical availability of turbine	Energy waste due to improper load balancing	Energy consumption (kWh)
Asset Performance	Wind turbine availability	Cable load balancing for increased availability	Utilization (%)

The different BCs illustrate the wide applicability of the generic proposed solution. The methodology for applying the proposed concept is presented next in the setting of the BC2. This application scenario addresses new product and customer support services for high voltage cables, to provide cable-monitoring services that help to redefine grid load and safety limits, enabling a significantly improved utilization of grid capacity. Especially the consistently increasing share of renewable energy in the European energy grid (e.g. by offshore wind parks), together with the decentralized and discontinuous production of renewable energy, will have a high impact on the grids, asking for a significant higher grid capacity (e.g. with respect to energy distribution and transport of electricity to energy storages). Due to this, electric utilities urgently need technologies and support tools facilitating an optimal usage of existing grid capacities by an improved load and security management.

Usage can be improved by better maintenance and monitoring. By “better maintenance” we understand avoiding unnecessary maintenance, or better predicting future maintenance needs. Monitoring can also be improved if the raw monitored data is processed before presenting it to the human operator, making decisions easier to take.

Targeted are supporting services easily adaptable to customer specific needs, facilitating analysis / optimization and maintenance of cable systems, with respect to an optimal and secure use of full cable capacity (up to 40% additional capacity). Thus, the new services will increase available grid capacities (measurable in a quantitative way for instance through the Asset Performance and Energy Waste KPIs); resources required for grid expansion will also be reduced (i.e. investments, raw material, demand for land, etc.), to achieve a European electricity grid ready for an increasing share of renewable energy. The most challenging problems in this context are on the one hand the required flexibility/adaptability of services to the diversity of customer needs and on the other hand the provision of online context information from the cable (e.g. conductor temperature / hotspot for detection of cable faults, etc.) and ambient condition (e.g. thermal characteristics of environment), required to analyse the maximum cable load. Moreover, knowledge on cable (e.g. dimension and construction, temperature profiles) and grid specific constraints (intelligent deduction of load predictions, etc.) are basic parameters.

The implementation of the proposed solution – the automatic adjustment of parameters based on changing context, e.g. changing ambient conditions – leads to minimization of errors and keeps the utilization high, as well as the overall quality. Furthermore, improved decision making is supported by taking into account previously taken decisions as well as current context, leading to better decision making proposals.

For this scenario, the context monitoring serves as a basis for identifying adjustment parameters. The monitored context refers in this BC to the environment of the cables, such as the material, their surroundings (soil, under water, in open air), the ambient temperatures, the voltages being transported by the cable. This context of the cables is used, together with previously taken load balancing decisions and their contexts, for ensuring the appropriate load balancing decisions will be made.

4. Conclusions

A novel approach for evaluating the performance of engineered products based on the whole life-cycle, so that product engineering teams can exploit this information to adapt the design, operation, maintenance and disposal strategies of products and processes is presented. The proposed solution addresses decision support in eco engineering systems, based on a context aware approach. The wide applicability of the proposed solution is presented, together with an example of customizing the generic solution for a specific industrial setting.

The proposed platform and services are under development. Early testing of first prototypes already indicated promising results of the proposed approach.

Further research will focus on advanced algorithms for continuous optimization.

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