

## COLLABORATIVE PRODUCT, PROCESS AND SERVICE DEVELOPMENT WITH ECO PROCESS ENGINEERING SYSTEM

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**Abstract:** The focus of engineering on achieving a superior product, processes and services from functional and economic factors is now shifting towards sustainable development. The aim is to provide customer business value and decrease environmental impacts. New easy to use tools are needed in the collaborative development of complex product-services. The EPES project carries out development to improve the sustainability performance of end-users products, operations and services. The Eco-Process Engineering System (EPES) provides a methodology and related ICT tools as a service for the development and management of product-services. This paper is an introduction to EPES system.

**Keywords:** Collaborative development, eco-efficiency, product service system,

### 1. INTRODUCTION

The focus of Product Service System (PSS) development is now shifting towards sustainable design which considers environmental, economic and social aspects. This can be achieved by integrating the sustainable aspects into the design and analysis tasks throughout the product's whole life-cycle. Life Cycle Thinking (LCT), Design for Environment (DfE) and eco-efficiency should be part of collaborative product, process and service development.

Eco-Process engineering system (EPES), as presented in this paper, is an ongoing development effort to bring new collaboration tools for managers, engineers and other stakeholders. Other similar development is reported for example in Reichel and Rünger, (2014). Eco-Process engineering system means here systematic, holistic eco-efficiency and eco-innovation aspects analysis in PSS development and management, and covers all life-cycle phases. EPES is an ICT tool and related application methodology (Sorli and Armijo, 2013, Schulze *at al.* 2013,2014). EPES system adds sustainability intelligence and eco-constraints to the decision making. Sustainability intelligence is a combination of business and manufacturing intelligence added with sustainability and PSS life-cycle aspects. The goal is to create more value with less environmental impact.

Virtual factories, e.g. extended enterprises with multiple stakeholders and actors, are the current way of working in the development of technical PSS. Creation of customer value by integrating products and services in a distributed organization creates new challenges in communication, process management and knowledge management. All actors in the value chain need a common goal and when PSS development requires shorter times, communication and collaboration become fundamental tools. Current development and management tools

are based on e.g. Product Life Cycle Management (PLM), various engineering analysis and optimisation tools, various Life Cycle Costing (LCC) tools, Enterprise Content Management (ECM), Computerized Maintenance Management Systems (CMMS) and so on. Some of those are static desktop applications potentially focusing only selected life-cycle phases and do not support collaboration. Coordinated evolution (co-evolution) of products, processes and services creates competitive advantage. Engineering knowledge management and knowledge sharing is an important issue in the collaborative work. The implementation of Engineering Knowledge Resources is documented in the literature e.g. Bermell-Garcia et al. (2012).

Selection of the best design among a set of alternatives is a very important task in the development stage of a product, process or service. The analysis for decision making needs to consider not only traditional cost and functional performance oriented parameters, but also eco-constraints that are derived from all the relevant stages in the product's whole life cycle. Modelling and simulation techniques are useful in the analysis of future effects and supports decision making. Integration of sustainability aspects to various simulation models is still rare, example of development are shown in Lind *et al* (2009), Heilala, *et al* (2012) and Thiede *et al.* (2013). Life Cycle Assessment (LCA) is commonly used for product system life cycle environmental analysis, but requires high expertise.

Introduction of multiple criteria and constraints to be considered increases the complexity of a decision-making process. As sustainability cannot be limited to a single stage of the life-cycle of an industrial product, it is always a very complex issue, and presents a need for complex multi-objective decision-making, in which compromises need to be made between mutually exclusive criteria. This also greatly increases the quantity of good-quality data that is needed to be presented to decision-makers. Decision makers need business, manufacturing and sustainability intelligence tools and methods.

Service-oriented ICT tools are one enabler for efficient networking and the PSS development. Due to increased product system complexity, distributed multidisciplinary engineering is often required. Easy-to-use tools are needed to enhance the efficiency, transparency and traceability of such multidisciplinary optimisation and decision-making processes. Business process management (BPM) of the multiple engineering processes is also required to orchestrate the activities carried by the various actors and stakeholders of virtual factory.

Above all, any tools or information deployed as part of Design for Environment (DfE) should be fully integrated in an existing design process, procedures and manuals. Environment should become a new key parameter to consider in decision-making, alongside technical performance, safety and cost [ACADEMY 2008]. In most engineering environments, designers need to be encouraged to integrate environmental aspects by increasing the availability of suitable tools and knowledge. In short, the main requirements should include: A simple and easy to use method; Availability of appropriate data; Clear and easily communicable results; and Traceable conclusions. The points presented here are the essentials of the EPES project and EPES system development.

## 2. EPES SYSTEM

The EC funded EPES project ([www.epes-project.eu](http://www.epes-project.eu)) carries out research and development to improve the sustainability performance of end-users operations, products and services. In the project, a software service platform prototype is created for bridging the gap between design-oriented tools, such as CAD and CAE, operations and service planning tools and tools for managing the business decision-making. The EPES system is an integrated Enterprise Content Management (ECM) and Business Process Management (BPM) platform that provides general advantages as an engineering and/or decision-making platform. Its focus is on efficient interdisciplinary co-operation, communication, data collection and management. It also serves as a tool for communication between the engineering community and the strategic decision-makers, allowing them to make informed decisions at the earliest stages of the PPS development and management. The platform provides functionalities for:

- **Knowledge Management**, in the form of an enterprise content management system, which is augmented with a semantic context database for providing additional meta-data.
- **Business Process Management**, in the form of a BPM platform on which complex processes can be modelled using BPMN 2.0.
- **IT service automation** that provides additional support for meta-data collection and processing and automating the execution of complex computational processes for producing the key performance indicators that are needed for decision-making.
- **Multi-objective simulation and optimization**, in the form of an integrated state-of-the art solution.

- **Business Intelligence**, in the form of a data integration and analytics platform.

EPES provides a comprehensive methodology and related ICT tools as a service for the development, optimisation and management of PSS life cycle (see Fig. 1.). EPES responds to the companies' need for moving from static isolated systems to a flexible system. The goal is to improve customer value, i.e. productivity, cost-efficiency, quality and eco-efficiency, i.e. reduce energy and resource consumption, emissions, and the use of hazardous substances through the holistic analysis of PSS and its life cycle.

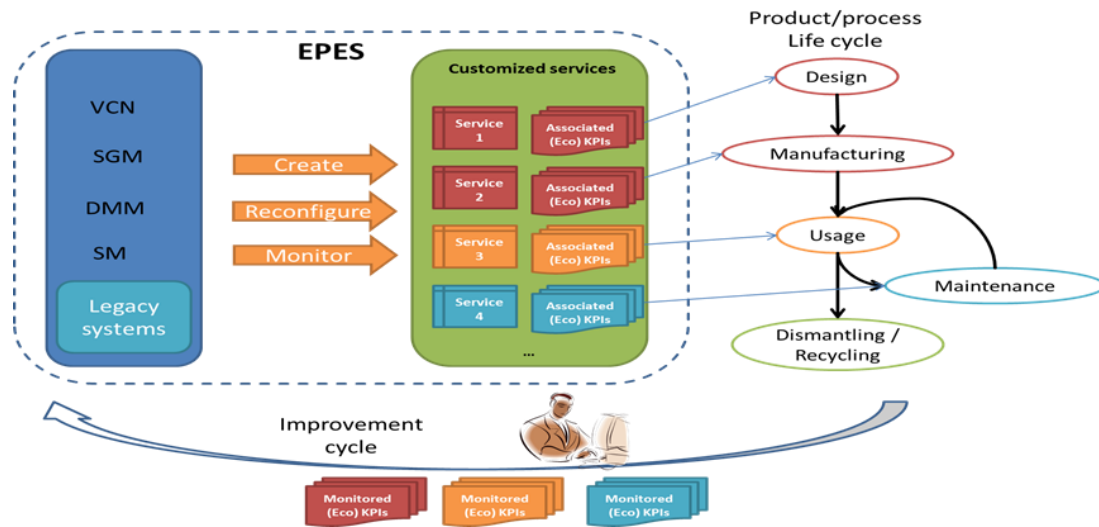


Fig. 1. EPES System.

The EPES system is built upon the following core services: Virtual Collaborative Network (VCN) , Service Generator Module (SGM) , Simulation Module (SM) and Decision Making Module (DMM) . Details are presented below (see also Fig. 1 and 2.).

*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 Graphical User Interfaces (GUI) 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 (LCI) data.

*Service GeneratorModule (SGM):* 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 SGM can also store / retrieve configurations in/from the Virtual Collaborative Network. Finally, the SGM allows identification of contextual information about EPES solution operators as well as connected legacy systems.

*Decision Making Module (DMM):* DMM is an interactive system helping decision-makers to use data and models to identify and solve problems and to make decisions. On the one hand, there are some traditional key performance indicators (KPI) for measuring the overall PSS 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, 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.

*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 Service Oriented Architecture (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.

## 2.1 EPES Architecture

EPES is structured by following a three layer architecture which keeps separated presentation, business logic and data management functions (see Fig 2.). It fully implements a service oriented approach, which represents several different process as services that are fully interoperable and allow further re-use for specific process reoccurrences. All layers of the EPES system concept are seen as a part of an overall service structure so that every component could interact with each other, but is additionally focused around specific transition services. EPES integrates existing tools, enhances further and provides them as configurable services for non-ICT experts. Existing enterprise “legacy” systems can be integrated to the system (Fig.1). These legacy systems can be product, engineering, manufacturing or operational software systems and related repositories.

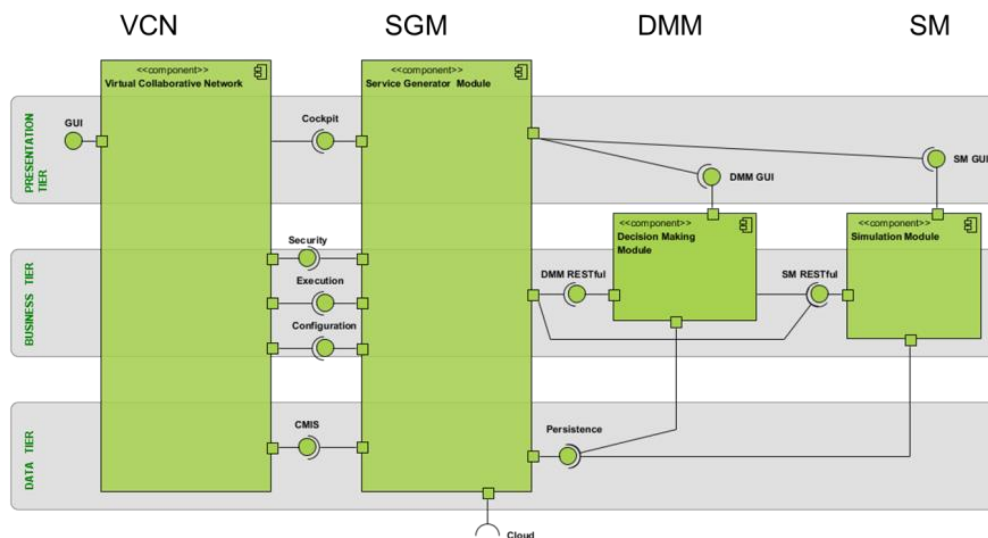


Fig. 2. EPES Architecture Schema.

The EPES platform is loosely coupled modular and scalable solution for flexibility supporting context aware services. This architecture support easy reconfiguration and scalability, e.g. the multiple simulation tools can be integrated and also replaced with other one. In order to provide maximum accessibility in a distributed environment, the platform is built to be operated in a strictly browser-based user interface.

## 3. EPES APPLICATION METHODOLOGY

The EPES application methodology presents how to use the EPES software platform and software components. The main steps in the EPES methodology are:

### Step 1: Collaborative Space definition -strategic planning.

- a. Identify business objectives for optimisation, evaluate improvement needs and constraints, define business process boundaries and goals with related strategic objectives and KPIs.
- b. Identify the product, service system life cycle phases that have effect on objectives.
- c. Plan Collaborative Space, define actors and stakeholders to be invited.

### Step 2: Collaborative project planning – tactical planning.

- a. Initiate a Collaborative Space, invite experts from the selected focus areas.
- b. Refine collaboratively objectives / constraints, and tactical KPIs to be measured.
- c. Plan project workflow with structured tasks definition, select business sub-process and drill-down to item level technical KPIs.

### Step 3: Business Process Management (BPM) – Operative and item level (Design – Modelling – Execution – Monitoring -Optimisation cycle) –operational level:

- a. Design, define and associate EPES services to monitor, analyse KPI and optimise the PSS.

- b. Modelling, set-up and configuration phase: to develop and configure services, simulation and optimisation models, to set-up/define and configure selected KPIs.
- c. Execution, run-time phase: to execute configure EPES solution, simulation models augmented with identified technical KPIs aiming at fulfilling item level objectives and constraints.
- d. Monitoring and Optimisation.

The main concept of organization of work in the EPES platform is the “collaborative space”. This is a concept that is quite similar to the concept of workspaces on platforms like Microsoft SharePoint, including both data and business process (or workflow) models, but provides additional functionality in the sense of configured computational services e.g. simulation and optimisation, that can operate directly on structured data files on the underlying content management platform.

The EPES system is a collaborative work environment, comprised of Collaborative Space, the portal to a PSS based industrial ecosystem. This work environment can be extended beyond the group of people who directly participate in the product development or management processes. This enables, for example, a more direct form of feedback from the users to the engineers and managers.

Each of the actors in the defined Collaborative Spaces system has a role. The role could be, for example, customer, an owner of the product, a user of the product, a service provider, component suppliers, subcontractors, a manufacturing or product-related engineer, a sales representative or a business decision-maker. Using the collaborative parts of the EPES system, any group of actors in the product service system community can distribute knowledge, collaborate, pin-point eco-constraints, bottlenecks and solve problems.

#### 4 EPES PROTOTYPE

The existing EPES prototype platform makes use of many existing solutions as parts of its integrated comprehensive platform. Additional software components have been developed in order to facilitate the integration of these existing solutions. These solutions include:

- **Alfresco:** An Enterprise Content Management (ECM) system
- **Activiti:** A business process modelling and execution framework
- **SOMO by ESTECO:** An optimization and simulation integration platform
- **Pentaho:** A business intelligence platform.

EPES system is an enterprise application, thus it needs customization and integration to existing legacy and other engineering systems, e.g. simulation tools. Typically service set-up, and integration requires expertise.

The EPES development has been industrial driven. The presented approach is being applied in three industrial business cases, to validate the proposed decision making solution within different application domains, as listed here.

*Business Case 1:* Engineering maintenance services for optimizing maintenance and increasing availability of wind turbines. The decision processes involved here deal with the best scheduling of maintenance tasks to be taken for optimal maintenance of multiple wind turbines. The decision making and optimisation constrains include, service and operation history, weather conditions and forecast, availability of service resources and so on.

*Business Case 2:* Power grid control systems for improved identification of improved monitoring of grid load and safety limits. Smart cable has features for temperature detection and monitoring at any point of the cable. Decision support methods are supporting the user in detecting trends in the grid load, ensuring thus that good load balancing decisions will be taken. Also new cable design is supported, e.g. material saving has multiple impacts on manufacturing, logistics and installation of cable network.

*Business Case 3:* Support for optimized design and manufacturing of aircraft wings. Here, the decision support system addresses the optimal layout of manufacturing facilities in the conceptual design phase. User can fix some of the parameters of the facility, i.e. work shifts, cycle times and capacity, and the optimization returns the numbers of required facility elements; resources, personnel etc. The production data is aggregated with sustainability data to enable optimization in environmental point of view.

## 5 AN ILLUSTRATED CASE STUDY ON CONCEPTUAL DESIGN PHASE

EPES system can be used for product, production process and system development, improvements analysis, operations planning and maintenance service management. This chapter illustrates how EPES system could be used for conceptual product assessment in the feasibility phase, before actual industrialisation (see Fig 3).

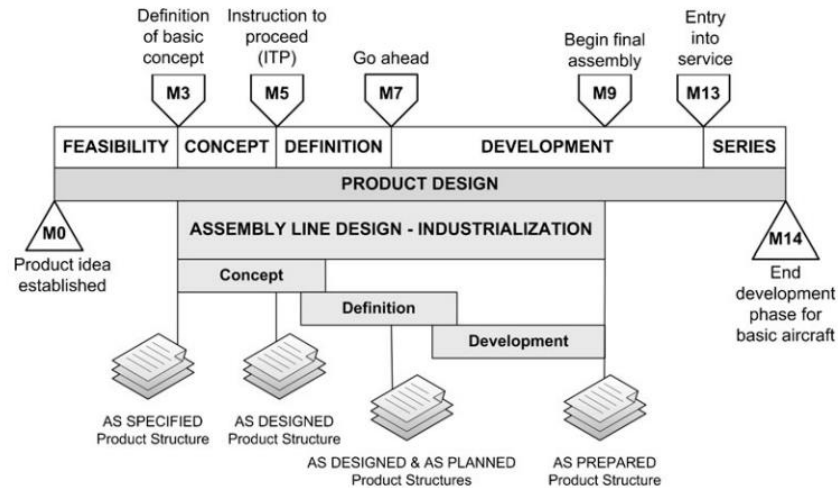


Fig.3. Product lifecycle and development milestones [Mas *et al.* 2012].

The EPES system provides new supporting services for sustainability assessment in Design for Manufacturing and Assembly (DFMA) using traditional manufacturing KPIs such as resource utilization, and production rate, and sustainability aspects of the production processes. In the illustrated case study, the analysis is based on Discrete Event Simulation (DES), Multi-Objective Optimization (MOO) and Life Cycle Inventory (LCI) calculation techniques. The essential questions answered through this assessment are:

- **Productivity KPIs:** What is the level of production rate and resource utilization for a product design using a given set of processes and resources? Or what is the optimal number of resources and tooling to achieve desired capacity?
- **Sustainability KPIs:** What are the energy and raw material consumptions, the emissions and the hazardous material waste resulting from the manufacturing for a design using a given set of processes and resources?

An aircraft wing design is a complex multi-engineering task. Wing architects make high-level decisions and other engineers provide domain-specific knowledge on: Aerodynamics, structural integrity, mechatronic design, design for manufacturing and assembly etc. The development process involves a lot of human interactions, task assignments and deliverables. The EPES system support design and manufacturing engineers to make informed decisions on the performance of design concepts from the manufacturing and sustainability perspective and enables the validation of production scenarios, e.g. future factories, at the early stages of design. The decisions have a big impact also on cost. For example in aeronautics industry, up to 80 % of the final aircraft cost are determined during conceptual phase and up to 30% of the final cost is due assembly operations [Mas *et al.*, 2012]. Thus the concepts need to be evaluated with care. The big challenge is low data quality, low fidelity information during the feasibility and concept phase.

The simulation result data can be further processes for other analysis purposes. The test case is planned to evaluate in relevant industrial environment. This EPES technology demonstrator is aimed to support the design for manufacturing (DFM) community to:

- Store and manage the manufacturing engineering knowledge that can be exploited into these low fidelity manufacturing assessment tools and collect the results generated by the tools into a single access point environment for all the stakeholders.
- Guide the design for manufacturing engineers to run the tools in controlled business process sequence that connects their inputs, the tools that process them and the outputs produced.

- Support the engineers involved in the process to integrate their software tools into an executable process that is either fully automated or manually assisted.
- Support the engineers in communicating the results of the manufacturing assessment process to people who make decisions that are based on them.

## 6. SUMMARY

EPES project objective is to develop a novel Eco Process Engineering System based on the Business Process Management (BPM) approach, which will constitute a comprehensive process-oriented platform, enabling dynamic composition of services, so called EPES Services that are adaptable to different products and operating conditions. The EPES solution also supports continuous improvement of processes and products in operation along the life cycle, applying optimization and simulation strategies for the operating phases and for improving future product designs.

Sustainability-related issues are important and they are adding heavily to the complexity of the design process. The amount of data that is needed for decision-making is growing and multiple parameters and constraints must be considered simultaneously. Because multiple engineering disciplines, multiple actors and multiple life cycle stages are involved in the goal of sustainability, multidisciplinary optimisation (MDO) and multi-objective optimisation (MOO) techniques can seldom be avoided. When these techniques and tools are provided as services, the transparency and traceability of the decision making processes can be improved.

The EPES platform is a tool for managing both technically and organizationally complex tasks in a distributed organizational environment, such as virtual factory. The platform combines existing enterprise IT tools into a platform that is flexible and configurable and supports the simultaneous management of knowledge from multiple viewpoints. This allows the extended enterprise use more efficiently the available engineering resources, both human and computational.

The EPES platform combines both data and procedures—both human and computer—into a package that allows its users to both codify and automate the various tasks that are necessary for addressing complex issues like sustainability. By using business process management and simulation automation techniques, the platform streamlines analysis processes by reducing repetition, especially in set-up tasks. Automating simulation and numeric optimization tasks also help to ensure that the outputs from a set of similar analysis tasks are consistent and thus easily comparable.

The focus of the EPES platform is on streamlining the processes that are necessary for addressing sustainability. Provision of engineering analyses, optimisation and simulation as services, e.g. automation of an engineering analysis processes using cloud computing, is one of the advantage of the EPES platform. When combined with knowledge management, communication and collaboration, business intelligence, and business process modelling and execution, a comprehensive platform is created for tackling the comprehensive problems for Product Service System (PSS) lifecycle optimisation.

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. EPES system can cover whole PSS lifecycle, and provide eco-efficient solutions:

- Optimized performance by design,
- dissemination of best environment practices within the supply chain,
- virtual collaboration network,
- sustainable and cleaner manufacturing processes,
- supporting efficient product operations, and
- recycling and re-use at end-of-life.

The assessment of a PSS with the EPES System can guide the development towards more sustainable solutions and provide information on the aspects that require further study. Instead of several desktop applications, engineering islands of analysis, the EPES system provides both integration and automation of the assessment methods that are necessary for tackling sustainability.

The EPES 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.

The maintenance and other services for industrial products, investment goods or design of complex, multi-disciplinary engineering products or other collaborative product process service development are promising application areas for the EPES system. The development will be assessed in the business cases listed earlier. The exploitation planning of the EPES system is ongoing.

**Acknowledgements.** The research presented in the paper has been carried out within the frames of the EPES, “Eco-Process Engineering System for Composition of Services to Optimize Product Life-Cycle” collaboration project, ([www.epes-project.eu](http://www.epes-project.eu)) co-funded by the European Commission under FoF-ICT-2011.7.3-285093 contract. The authors wish to express the acknowledgement to EC for the support and to all project partners for their contributions during the development presented in this paper. This document does not represent the opinion of the European Community, and the European Community is not responsible for any use that might be made of its content.

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