Requirements Analysis and Definition for Eco-factories: The Case of EMC2

Marco Taisch and Bojan Stahl

Politecnico di Milano, Department of Management,
Economics and Industrial Engineering, Milan, Italy
{marco.taisch,bojan.stahl}@polimi.it

Abstract. Climate change mitigation and the EU2020 strategy foster energy efficiency in Europe's future manufacturing landscape. These challenges make high demands to SMEs as well to MNCs. The paper gives insight to an approach on Eco-factories based on the EU-funded FP7 project EMC2. Eco-factories will enable the quantum leap in integrating environmental issues in brownfield and greenfield factory planning and factory operation. The paper focuses on the identification, structuring and definition of requirements for Eco-factory simulation approaches. Requirements for developing a simulation environment for integrating energy and material flows for detailed analysis but also wide user spectrum is presented. The paper shows that demands are twofold requesting integrated, modular and detailed simulation solutions as well as emphasize on user-friendliness and low complexity.

Keywords: eco-factory, energy efficiency, sustainable manufacturing, simulation requirements, energy flow.

1 Introduction

Climate change mitigation and security of supply are the major drivers for raising, keeping and enhancing the attention towards energy consumption on European level, addressing policy-makers, industry and society in the same way [1]. Energy consumption implies severe ecological consequences such as global warming and resource depletion on the one hand, and being dependent of supply from non-European countries may lead to potential economic and social risks.

Industry is facing a strong economic pressure which might endanger the global competiveness. Energy and raw material prices are steadily increasing in the last years, and the public awareness for green products is steadily rising with more enlightened customers. Consequently, awareness towards energy efficiency is strongly addressed by European policy-makers [2]. The European 2020 strategy defined several eco-targets to be reached by 2020, i.e. the reduction of emissions by 20%, and the reduction in primary energy of 20% to be achieved by improving energy efficiency, while securing the competiveness of European companies at the same time.

C. Emmanouilidis, M. Taisch, D. Kiritsis (Eds.): APMS 2012, Part I, IFIP AICT 397, pp. 111–118, 2013.

Production processes are the backbone of the industry in Europe regarding economic success but also regarding environmental and social impact. Resources and energy are the major inputs for the transformation processes to create value. However, creating value by the input of resources and energy leads also wastes in terms of losses, heat, and emissions.

Together with households, commercial and transportation in the domain of energy consumption, manufacturing is considered as a main contributor, with being responsible for approximately 37% of primary energy consumption on global scale. At European level, industry is responsible for about 40% of the electricity consumption [3]. Future manufacturing paradigm should therefore be built on two pillars: avoiding material and energy waste through increased efficient production and avoiding energy and material consumption with harmful impact on the environment.

Diverse studies have been carried out to highlight the improvement potential within industry. The international Energy Agency has stated in their Energy Efficiency Policy Recommendation that potential savings sum up to 18.9 EJ/year and 1.6Gt CO2/year by 2030 [4]. A German-lead consortium of the Fraunhofer Gesellschaft highlights the major potential of increased production process efficiency to optimize the environmental as well as economic performance of companies [5]. A consultation group operating on European level has identified saving potentials of 10-40% in manufacturing in their “Smart Manufacturing” report [6]. A similar study carried out on country level in Germany has likewise identified a saving potential of 10-30% on energy consumption [7].

Production system simulation incorporating environmental perspectives is seen as one appropriate tool in the design and optimization of manufacturing systems towards energy efficiency. The paper presents an approach for defining requirements on such simulation approaches by applying a requirements engineering approach. The aim is to gain a detailed insight into what developers, stakeholders and users see as main features to be implemented in order to support the successful application in industry and research.

2 Methodology

A requirement can be defined as a need that a specific product shows by attributes, characteristics or specific qualities that the end product should possess [8]. According to [9], requirements engineering regards establishing and documenting software requirements. Through this process it is possible defining what the system should be able to do and the constraints in which it needs to operate. This process consists of four major steps: elicitation, analysis, specification, verification and management. The requirements management is represented by the planning and controlling of the other steps of the requirements engineering phase.

In the elicitation phase the problem to be solved is defined through the identification of the boundaries and the stakeholders’ and goals’ definition. It is the first step of the requirements engineering. The information gathered in this phase need to be interpreted, analysed and validated [10]. Different techniques exist to perform the elicitation phase, e.g. interviews, scenarios creation, prototypes, meetings and observation.

The second phase, analysis, potential conflict by different requirements sources could imply need to be solved. Consequently this step deals with the requirements' conflicts detection and resolution. The conflict resolution is lead by negotiation. Furthermore, this is the phase in which the system bounds are discovered together with the interactions with the environment [8].

In the documentation phase the requirements identified are specified and formalized. It is important that the requirements can be traced in order to be easy to read, understood and navigated [10]. The output of this process is a requirements document.

Finally, in the validation the requirements are checked in order to find out further omissions and conflicts. In this phase it is checked if the requirements document created is consistent and complete and requirements priorities are attributed. This is the step into which the quality of the model developed is validated [8].

In order to be complete, the process of requirements engineering should consider all the important sources of requirements from which the requirements are gained. These sources can be in conflict among them and part of the requirements engineering is, for this reason, represented by negotiation and prioritization activities. Each step is described in detail in the subsequent sections.

3 Elicitation

In this step of the simulation requirements engineering, the requirements are collected from different sources and different stakeholders. It is the first phase of the requirements engineering and it helps the developers of the product in understanding the problem. The stakeholders from which the requirements are developed may belong to different categories. They can be end-users, customers, regulators, developers, neighbouring systems and domain experts. In this case the requirements have been collected from three sources. The first one is represented by a classical literature review of papers dealing with simulation of energy in manufacturing, in order to take into account from them the general simulation requirements to be used in the model development. The second type of source is represented by the opinions of experts, stakeholders and users, represented by the partners and consortium of the EMC2-Factory project. The last source is represented by the developers themselves by having a visionary idea of building a holistic simulation model for combining energy and material flow simulation.

Different works available in the literature have been reviewed according to their postulations of requirements for "integrating energy, material and building simulation which resulted in total in 52 requirements [12]-[31]. 42 requirements have been identified by the partners and consortium members. For this reason questionnaires were provided to the stakeholders in order to capture their opinion. The developers themselves provided 17 more requirements.

Summarized, 111 requirements have been identified in total from the literature review, the stakeholder consultation and the internal development team. The requirements present overlaps and conflicts which need to be managed in order to avoid repetitions and contradictions for the final requirements which is done in the next step.

4 Analysis

In the second step of the requirements methodology applied, two main activities are performed: the requirements classification and the requirements negotiation. In the classification of the requirements, they are divided into distinguishable categories while in the negotiation the resolution of the conflicts has been conducted.

The following paragraph identifies the categories in which the requirements are classified and divided. The simulation requirements were divided in four categories: general, functional, non-functional and implementation requirements. General requirements are high level conceptual requirements. Implementation requirements focus on the system-side conceptualization of the simulator. Functional requirements define what the simulator should be able to perform. Non-functional requirements describe characteristics linked to the way in which the simulator performs its functions.

According to the mentioned categories, the requirements listed in the requirements elicitation step have been divided and categorised, each one in one of the above mentioned categories. Hence, the requirements with the same or similar meaning and scope have been joined together and the ones in conflicts have been resolved. Starting from the 111 requirements identified in the elicitation phase it has been possible to group and merge them according to the scope and the meaning they presented and to arrive until 33 final requirements. The meaning and the scope of each requirement has been identified by checking how each requirement fit with the simulation purpose. The set of requirements obtained at the end of the analysis process are listed and explained in the documentation phase in which all the requirements identified are explained and classified.

5 Documentation and Validation

Documenting the requirements is the fundamental condition to the requirements handling. In this phase the structure of the requirements document is developed. The two tables below provide a short excerpt of the documentation of the requirements defined in the analysis step.

The last phase of the requirements engineering is represented by the validation. This steps deals with the analysis of the document produce in the documentation phase in order to be sure that it represents the right requirements in the most complete way. In this phase the focus is on looking for mistakes, errors or lack of clarity. According to [11], the requirements validation needs to be performed in order to be sure that the requirements are: unambiguous, allowing only a single interpretation; concise; finite; measurable; feasible to be implemented with the available technologies; traceable. This phase has been performed, however results are not explicitly mentioned here.

Table 1. Functional Requirements

Requirements	Description
Assessing different kind of KPIs	The KPIs' framework should include the evaluation of production, energy and environmental KPIs both real-time and post-processing in order to allow timely decisions oriented to the reduction of the energy costs and to the decrease of the environmental impact.
Considering production assets and technical building services	It means modeling and simulating not only the energy consumption of the production-related assets but also of the non-productive equipments, like the central TBS and the periphery systems, supporting their dimensioning and optimization.
Supporting the dynamic connections of elements and interrelations	Representing in the simulation the dynamic connections existing among production assets, periphery systems and central technical building services.
Bringing inside the states based energy consumption calculations	It underlines the importance of implementing energy calculations during the simulation running basing them on the energy consumption associated to entities' states; representing the basis for non-productive states energy consumption reduction.
Interfacing with production control policies	It means supporting the connection of the simulation with production control policies at machines' coordination level, oriented toward the energy consumption reduction and able to influence the equipments' states.
Preventing energy peaks	It underlines the important of intervening real time on the manufacturing through control policies when the energy consumption shows rapidly increases.
Including multi-product perspective	Including product type control policies and supporting the different product type's identification during the simulation.
Supporting green oriented perspectives	Enabling green oriented decisions in terms of scheduling, production configurations.
Allowing different levels of energy consumption calculations	It underlines the importance for the simulation model to calculate energy consumptions starting from the machine level and arriving till the factory one.
Considering different energy carriers and supply systems	It stresses the high contribution to the holistic perspective given by the consideration of different energy carriers and different periphery systems.

Table 2. Non-functional requirements

Requirements	Description
Creating a simple and controllable solution	It underlines the need of a manageable solution, easy to be controlled and customized.
Integrated solutions	It means integrating different tools together in order to develop an interoperable simulation approach.
Activating Plug-ins functions	It sets the need to have functions which can be activated through plug-ins.
Using graphical interface	The functionalities of the simulation model are shown in a graphical interface.
Optimizing ease of use	The requirement stresses the relevance of having a tool easy to be used.
Increasing speed	It refers to the required increase of speed in the simulation running.
Increasing the user-friendliness	High user friendliness makes the model easier to be used and more attractive.
Supporting step-by-step guiding procedures	It underlines the importance for the model to be equipped with exhaustive descriptions.
Including stochastic inputs and unpredictable events	The model should allow the possibility to insert input data which are not deterministic.
Increasing the level of data detail	The model should support the highest possible level of data detail.

6 Summary and Outlook

The definition of functional requirements for simulation of eco-factories is a first step to guide the way from traditional factory design and operations to eco-enabled competitive factories. The functional requirements build the backbone of the definition of a holistic reference model for eco-factories which serves on the one hand as a meta-model for future activities in the project itself and on the other hand as an enabler for a comprehensive guide or toolkit to support industrial implementation by hands on suggestions. The functional requirements need to be implemented into a discrete event simulator.

This paper presented the requirement engineering process as an initial step before the development of a discrete event simulation environment which combines energy and material flow simulation. Analyzing the requirements leads to the following conclusions. There is an increasing demand in adapting simulation applications to a larger user group, hence giving support by pre-defined objects and decreasing the modelling complexity. It is demanded to increase user-friendliness and keep solutions easy and simple. On the other side the integration of different tools and increase of level of detail of data are requirements which may result in a stress-field in accomplishment. The functional requirements are widely focused on the increase of detail concerning energy considerations and widening the scope of traditional production asset simulations taking into account periphery systems and central technical building services.

Finally it can be summarized that literature and stakeholders see an increasing interest in making energy simulations in manufacturing more comprehensive, detailed, but also simple. The requirement engineering process served as an initial step of a simulation environment development approach. The next major phase includes the conceptual design of a simulation environment which combines material flow and energy flow in production systems taking into account production assets as well as technical building service and being applicable on different scales in the factory.

Acknowledgements. The introduced requirements and results were developed within the research project EMC2 (Eco Manufactured transportation means from Clean and Competitive Factory) funded by the European Commission within FP7 (285363).

References

1. Eurostat. Measuring progress towards a more sustainable Europe. European Commission, `http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-77-07-115/EN/KS-77-07-115-EN.PDF`
2. European Commission: EUROPE 2020 A strategy for smart, sustainable and inclusive growth (2010)
3. European Environmental Agency, `http://www.eea.europa.eu/`
4. International Energy Agency: Energy Efficiency Policy Recommendations Worldwide Implementation (2008)
5. Fraunhofer Gesellschaft: Energieeffizienz in der Produktion - Untersuchung zum Handlungs- und Forschungsbedarf (2008)
6. ICT and Energy Efficiency - Consultation Group on Smart Manufacturing: Report: Energy Efficiency in Manufacturing - The Role of ICT (2008)
7. Seefeldt, F., Wünsch, M.: Potenziale für Energieeinsparung und Energieeffizienz im Lichte aktueller Preisentwicklungen, Prognos AG (2007)
8. Sawyer, P., Kotonya, G.: Software Requirements. SWEBOK (2001)
9. Thayer, R., Dorfman, M.: Software Requirements Engineering, 2nd edn. IEEE Computer Society Press, Los Alamitos (1997)
10. Nuseibeh, B., Easterbrook, S.: Requirements Engineering: A Roadmap. In: ICSE 2000 Proceedings of the Conference on the Future of Software Engineering, pp. 35–46 (2000)
11. Westfall, L.: Software Requirements Engineering: What, Why, Who, When, and How (2006)
12. Thiede, S.: Energy Efficiency in Manufacturing Systems. Springer, Berlin (2012)
13. Heilala, J., et al.: Simulation-based sustainable manufacturing system design. In: Winter Simulation Conference, pp. 1922–1930 (2008)
14. Seow, Y., Rahimifard, S.: A framework for modelling energy consumption within manufacturing systems. CIRP Journal of Manufacturing Science and Technology 4(3), 258–264 (2011)
15. Rahimifard, S., Seow, Y., Childs, T.: Minimising Embodied Product Energy to support energy efficient manufacturing. CIRP Annals - Manufacturing Technology 59(1), 25–28 (2010)

16. Solding, P., Petku, D.: Applying Energy Aspects on Simulation of Energy-Intensive Production Systems. In: Proceedings of the 2005 Winter Simulation Conference, pp. 1428–1432 (2005)
17. Solding, P., Thollander, P.: Increased energy efficiency in a swedish iron foundry through use of discrete event simulation. In: Proceedings of the 2006 Winter Simulation Conference, pp. 1971–1976 (2006)
18. Solding, P., Petku, D., Mardan, N.: Using simulation for more sustainable production systems – methodologies and case studies. International Journal of Sustainable Engineering 2(2), 111–122 (2009)
19. Weinert, N., Chiotellis, S., Seliger, G.: Methodology for planning and operating energy-efficient production systems. CIRP Annals - Manufacturing Technology 60, 41–44 (2011)
20. Hesselbach, J., et al.: Energy Efficiency through optimized coordination of production and technical building services. In: LCE 2008 - 15th CIRP International Conference on Life Cycle Engineering, Sydney, pp. 17–19 (2008)
21. Löfgren, B., Tillman, A.-M.: Relating manufacturing system configuration to life-cycle environmental performance: discrete-event simulation supplemented with LCA. Journal of Cleaner Production 19(17-18), 2015–2024 (2011)
22. Johansson, B., et al.: Discrete event simulation to generate requirements specification for sustainable manufacturing systems design. In: Proceedings of the 9th Workshop on Performance Metrics for Intelligent Systems - PerMIS 2009, pp. 38–42. ACM Press, New York (2009)
23. Dietmair, A., Verl, A.: A generic energy consumption model for decision making and energy efficiency optimisation in manufacturing. International Journal of Sustainable Engineering 2(2), 123–133 (2009)
24. Dietmair, A., Verl, A., Eberspaecher, P.: Predictive Simulation for Model Based Energy Consumption Optimisation in Manufacturing System and Machine Control. In: Flexible Automation and Intelligent Manufacturing (FAIM), pp. 226–233 (2009)
25. Wohlgemuth, V., Page, B., Kreutzer, W.: Combining Discrete Event Simulation and Material Flow Analysis based on a Component-Oriented Approach to Industrial Environmental Protection. Environmental Modeling and Software 21, 1607–1617 (2006)
26. Cannata, A.: A Methodology to enhance Energy Efficiency at Factory Level: Improvements for sustainable Manufacturing. Dissertation, Politecnico di Milano (2011)
27. Cannata, A., Karnouskos, S., Taisch, M.: Energy efficiency driven process analysis and optimization in discrete manufacturing. In: 2009 35th Annual Conference of IEEE Industrial Electronics (2009)
28. Cannata, A., Taisch, M.: Introducing Energy Performances in Production Management: Towards Energy Efficient Manufacturing. In: Vallespir, B., Alix, T. (eds.) APMS 2010. IFIP AICT, vol. 338, pp. 168–175. Springer, Heidelberg (2010)
29. Shao, G., Bengtsson, N., Johansson, B.: Interoperability for Simulation of Sustainable Manufacturing. In: Proceedings of the 2010 Spring Simulation Multi-Conference (SpringSim 2010), pp. 1–8 (2010)
30. Shao, G., Kibira, D., Lyons, K.: A virtual Machining Model for Sustainability Analysis. In: Proceedings of the ASME 2010 International Design Engineering Technical Conference & Computers and Information in Engineering Conference, pp. 1–9 (2010)
31. Prabhu, V.V., Cannata, A., Taisch, M.: Simulation Modeling of Energy Dynamics in Discrete Manufacturing Systems. In: Borangiu, T., et al. (eds.) 14th IFAC Symposium on Information Control Problems in Manufacturing (INCOM), Bucharest (2012)
32. Prabhu, V.V., Jeon, H.W., Taisch, M.: Modeling Green Factory Physics – An Analytical Approach. In: 2012 IEEE International Conference on Automation Science and Engineering (CASE), pp. 46–51 (2012)