Improving Manufacturing System's Lifecycle: Proposal of a Closed Loop Framework

Daniele Cerri, Sergio Terzi

Improving Manufacturing System's Lifecycle: Proposal of a Closed Loop Framework

Daniele Cerri, Sergio Terzi

Politecnico di Milano, Department of Management, Economics and Industrial Engineering
Piazza Leonardo da Vinci, 20133, Milano, Italy
daniele.cerri@polimi.it
sergio.terzi@polimi.it

Abstract. Over recent years, the context where companies operate has dramatically changed, forcing the business models' revision in order to survive in the market. Nowadays, in the manufacturing system's context, customers are focusing its attention more and more on an efficient and effective management of system lifecycle. Methodologies such as Life Cycle Costing and Life Cycle Assessment are useful to evaluate costs and environmental impacts generated along the whole lifecycle, however they are not sufficient to improve system lifecycle. The aim of the paper is to propose a closed loop framework in order to improve lifecycle of manufacturing systems.

Keywords: Life Cycle Assessment, LCA, Life Cycle Costing, LCC, Closed Loop, Framework, System Lifecycle.

1 Introduction

During the last years, the context where companies operate has dramatically changed. Cost pressure of emerging countries, more strict environmental regulations and new customers' needs have completely changed the market and the leverages that before regulated it.

In order to compete and survive in the global market, companies need to revise their business models, changing their paradigms and including new leverages.

Nowadays, in the manufacturing system's context, customers are focusing its attention more and more on an efficient and effective management of system lifecycle. Indeed, customer evaluates different proposals by different suppliers, in order to choose the best one. They consider different factors: one of the most critical is the lifecycle costs (and the lifecycle environmental impacts).

In this context, suppliers are forced to pursue a product lifecycle approach for their systems, in order to hit the customers' expectations. In order to evaluate costs and environmental impacts along the whole lifecycle, suppliers can be supported by two well-known methodologies: the Life Cycle Costing (LCC), to evaluate the

lifecycle costs, and the Life Cycle Assessment (LCA), to evaluate the lifecycle environmental impacts. However, these methodologies are useful only to evaluate the economic and environmental dimensions, but they are not able to support the lifecycle improvement of manufacturing systems.

In order to cover this gap, the paper proposes a closed loop framework to improve lifecycle of manufacturing systems. Section 2 shows the theoretical background, while Section 3 describes the Closed Loop Framework. Section 4 shows a possible application in a real industrial context. Finally, Section 5 concludes the paper, highlighting next steps.

2 Theoretical Background

This section reports the theoretical background behind the proposed closed loop framework. Figure 1 shows steps to define the theoretical background.

Fig. 1. Theoretical background steps

First of all, product lifecycle has been defined.
The lifecycle of a product can be divided into 3 phases:
- Beginning of Life (BoL): design and manufacturing of the product
- Middle of Life (MoL): use of the product (and all the services connected)
- End of Life (EoL): in this phase there can be 4 cycles:
  - Reuse: the product is reused as is, therefore it gets back in Middle of Life phase
  - Remanufacturing: the product is remanufactured, therefore it gets back in Beginning of Life phase, in the Manufacturing phase
  - Recycling: the product is recycled, transforming it into materials. The materials can get back in Beginning of Life phase, in Manufacturing phase
  - Disposal: the product is disposed and therefore it doesn't get back into the life cycle flow [1].

Using the GERA Model [2], instead, it is possible to describe in a more detailed way the lifecycle of manufacturing systems. It identifies the following stages: identification, concept, requirements, preliminary design, detailed design, implementation, operation, possible redesign activities, decommission. Therefore, Beginning of Life phase is represented by identification, concept, requirements, preliminary design, detailed design and implementation stages; Middle of Life is

represented by operation and possible redesign activities stages; finally, decommission stage represents the End of Life phase.

Usually, the lifecycle of an industrial system starts when the customer sends a request for tender to the supplier (industrial systems' manufacturer). Customer and supplier work together during the first phases (identification, concept and requirements). Then the supplier realizes a preliminary design of the industrial systems, defining the lifecycle costs and environmental impacts. Usually, preliminary design ends with the submission of tender. Customer evaluates different proposals received by different suppliers, and the best one gets the order. Different key factors are used to evaluate the proposal: one of the most critical is the lifecycle costs (and lifecycle environmental impacts). If the order is won, manufacturing system is designed in detail, and then installed at customer plant. Finally, the system fully operates until decommission.

As previously mentioned, lifecycle costs and environmental impacts are key factors to win the order. In order to evaluate costs and environmental impacts generated along the whole lifecycle, two methodologies have been identified: Life Cycle Costing (LCC) and Life Cycle Assessment (LCA).

Lifecycle cost is defined as the total cost of ownership of machinery and equipment, including its cost of acquisition, operation, maintenance, conversion, and/or decommission [3].

Life Cycle Assessment, instead, is a methodology to assess environmental impacts associated with all the stages of a product's life from-cradle-to-grave [4].

Analysing LCC and LCA methodologies, some gaps have been identified.

First of all, LCC and LCA methodologies are very good in comparison and estimation of few products or alternatives; however, when the number of alternatives increases, they are not able to support decisions and decision makers in a good way, especially in the case of manufacturing systems.

Furthermore, LCC and LCA methodologies have to be integrated with systems able to collect data from the field, with the aim to maintain under control costs and environmental impacts generated along the operation phase. Collection of data from the field enables also the extraction of valuable knowledge for designers, in order to improve design and sustainability of next manufacturing systems.

In order to cover these gaps, next section proposes a closed loop framework in order to improve sustainability issues.

3 Closed Loop Framework

In this section, a closed loop framework to improve sustainability issues is presented. Figure 2 describes the framework in a graphical way. Closed Loop Framework is built on GERA model, considering all the stages identified. Lifecycle stages are divided into three macro-phases: (i) Beginning of Life, which identifies design and manufacturing of the system; (ii) Middle of Life, which identifies

the operation stage and related services, besides the possible system re-design; and (iii) End of Life, which identifies the system decommission. Blue arrows identify the information flow, while red boxes report tools associated with the lifecycle stage. Tool about End of Life is in a grey box because it has not been yet developed. Configurator and Data Collection tools have been developed to cover gaps identified in the previous section, in order to support the decision makers in their activities. Briefly, Configurator tool's aim is to support the identification and creation of the optimal lifecycle oriented configuration, in terms of costs and environmental impacts, able to satisfy the customer's requirements. Data Collection tool's aim is, instead, to extract valuable knowledge from the tons of data from the field, both to maintain under control the existing system and to design next manufacturing systems. The aim of the future End of Life tool will be to understand the best End of Life option for each component of the manufacturing system.

As previously mentioned, blue arrows represent the information flow. Till now, the focus was on data and information from the field, during the utilization phase of the system. Indeed, to extract valuable knowledge from the field is useful for both Beginning of Life, Middle of Life, and End of Life phases, because it enables: (i) a design improvement of next manufacturing systems (BoL), (ii) a better management of the system during the operation phase (MoL), and (iii) a better understanding of the wear state of the entire system (EoL).
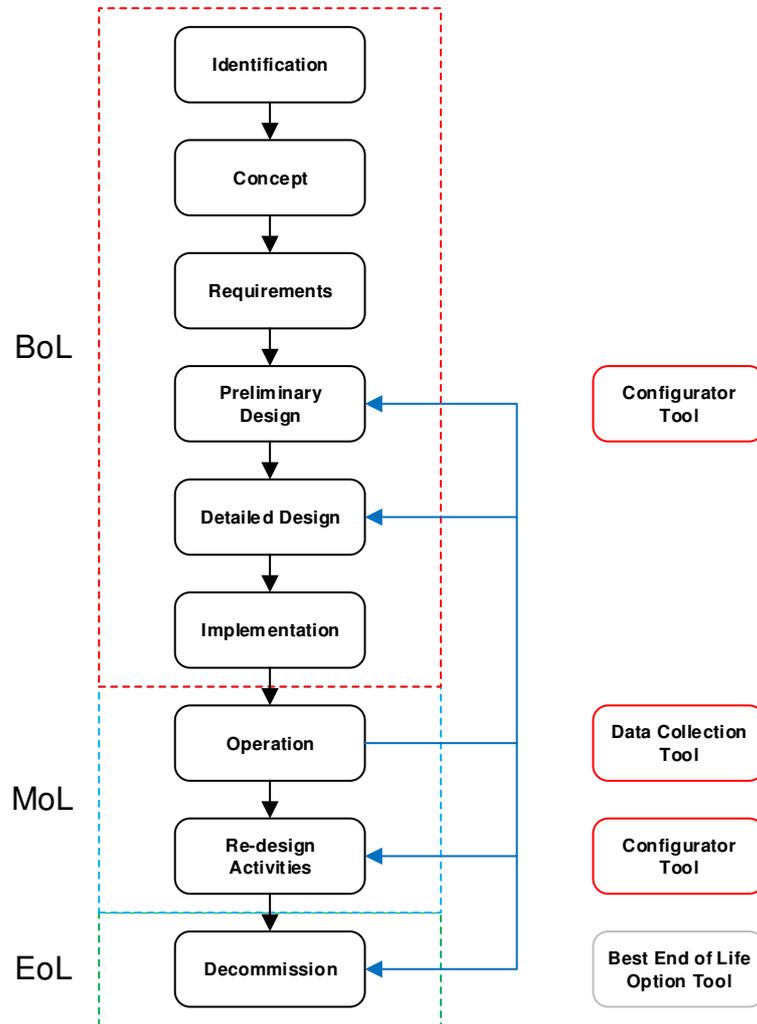
Fig. 2. Closed Loop Framework

Configurator tool [5, 6] has been developed with the aim to support designers and system engineers in their activities during the preliminary design, in order to create and identify the optimal lifecycle oriented configuration, minimizing lifecycle costs and environmental impacts and satisfying customer's requirements. Therefore, the tool returns the optimal configuration, in terms of which components have to be installed on manufacturing system, and lifecycle costs and environmental impacts values. Configurator tool is built on genetic algorithm, which has been chosen for three main reasons: (i) it is more efficient than others when the number of variables increases (for example, an assembly line for the automo-

tive sector can usually be composed up to 100 stations); (ii) it presents no problem with multi-objective optimization and (iii) it is suitable for applications dealing with component-based systems (a product could be seen as a chromosome and its components as genes).

Genetic algorithm has to solve a problem with two objectives, which are the minimization of lifecycle costs and the minimization of lifecycle environmental impacts. The objectives consider only the costs and the environmental impacts specified by the customer, in order to deliver the proposal that better fits with the customer's requirements. Furthermore, it is possible to implement constraints in the problem. As for the objectives, constraints depend on customer's requirements. The algorithm return the optimal configuration of the system, identifying which are the components that minimize the lifecycle costs and the lifecycle environmental impacts, satisfying the constraints. For example, in an assembly line, the algorithm suggests which station, among automatic, semi-automatic or manual, is the optimal one. Being a multi-objective problem, it is possible to have a trade-off between the two objective and, therefore, to have more than one optimal configurations. Decision makers have to choose which optimal configuration better fits with customer's requirements.

The tool has a user interface (Figure 3), divided into two spaces, one to define the objective functions and the other one to define the design of the system (how many components, how many alternatives for each components). In a window user has the possibility to import a *.xls file or to insert data. Data are then validated and checked. Finally tool executes the genetic algorithm. Results are displayed in the Output window, which reports: (i) the value of the objective functions and (ii) all the optimal configurations, showing which components are selected to realize the system.

Fig. 3. Configurator Tool's User Interface

Data collection tool is a simple tool with the aim to extract valuable knowledge from the tons of data collectable from the field, during the operation phase. Indeed, it is possible to collect tons of data from the different sensors installed on the system's components, machines or stations. The issue is how to use these data in a valuable and useful way, returning to decision makers structured knowledge. Decision makers can interrogate the database, through a user interface, in order to receive the desired information, through the back end logic, able to answer to the interrogations. Back end recovers data and information from the PLC databases, which collect information by different system's sensors.

The main benefits of this tool are: (i) the real time monitoring of the system and (ii) valuable knowledge for the design improvement of the next systems.

The real time monitoring enables to understand if lifecycle costs and environmental impacts, besides the technical requirements, have strong deviations rather than the estimated values during the preliminary design phase, through Configurator tool. Furthermore, Data Collection tool helps to find the right corrective actions, in order to reduce the deviations.

The tool returns valuable knowledge, useful for the design of the next system. It enables system improvements, in terms of reduction of costs and environmental impacts, understanding which are the most critical components / stations / machines.

The tool is able to summarize the main system's parameters in order to verify quickly performances of each system machine / station. It is possible to set different indicators, according to the industrial needs, like average cycle time, mean time between failures (MTBF) and mean time to repair (MTTR), availability and overall equipment effectiveness (OEE).

Decision makers can visualize detailed information, visualizing different pages that recap the main performances in a numerical and graphical way. For example, the page about availability shows the parameters of: availability, mean time between two failures (MTBF) and the mean time to repair the problem (MTTR). Furthermore it shows the machine states: working, failure, blocked, starved, excluded, intervention, over cycle time and tool change.

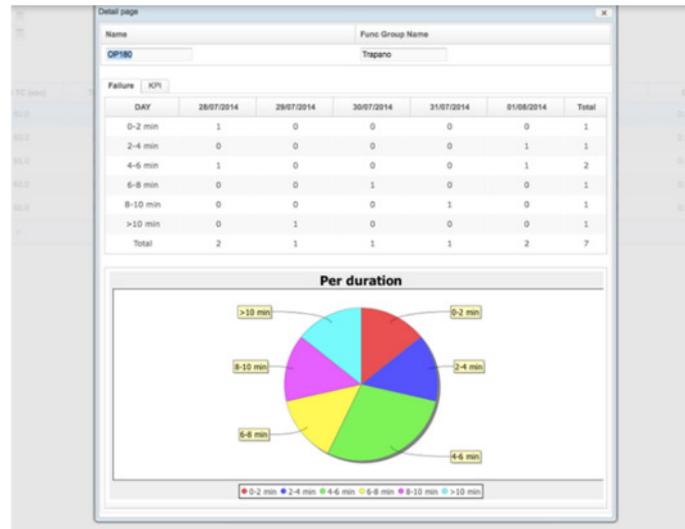Figure 4 shows a graphical report of the tool.

Fig. 4. Example of Data Collection tool's output

4 Application

An Italian global supplier of industrial automation systems and services mainly for the automotive manufacturing sector is applying Closed Loop framework. The company offers its proficiency as system integrator and its complete engineering solutions, from product development and manufacturing, to assistance to the production start-up phases, equipment and full plant maintenance activities. Lifecycle of a manufacturing system follows the GERA Model [10] with a good approximation (see Figure 5).

Fig. 5. System lifecycle within the company

Even in this case, customer evaluates different proposal after the concept phase, and the best one in term of lifecycle costs (and lifecycle environmental impacts) gets the order.

Company is testing Configurator and Data Collection tools. Till now, Configurator tool has been tested on an industrial case provided by the company, which was a fraction of an engine assembly line. Data collection tool, instead, has been tested within the company, in a laboratory that simulates the behaviour of a production system. At the end of the test, an evaluation has been conducted via quali-

tative questionnaire. This first evaluation enables to understand strengths and weaknesses of the framework, in order to improve it in the next steps. Furthermore, other tests have been planned, in order to evaluate the goodness of the framework. About Configurator tool, it will be tested on an assembly line composed by 20 stations. Data Collection tool, instead, will be implemented and tested on a real assembly line installed in Poland. At the end of these tests, a complete and extended evaluation of the framework will be conducted.

5 Conclusions

The aim of this paper is to propose a closed loop framework in order to improve lifecycle of manufacturing systems. Indeed, in the current context, customer evaluates different proposals by different suppliers, choosing the best one. One of the most critical factor considered by customers is the lifecycle costs, and in some cases they consider also the lifecycle environmental impacts.

Section 2 shown the lifecycle of a system and the lifecycle methodologies identified, which are Life Cycle Costing and Life Cycle Assessment. These methodologies need to be supported by other tools, in order to be effective and efficient. For this reason, Section 3 describes the proposed Closed Loop Framework, explaining tools and information flow. Finally, Section 4 briefly presents a work in progress application of the framework on a real industrial context.

Further steps are necessary to complete the framework.

First of all, it is necessary to identify or develop a tool for the End of Life of a system, in order to support decision makers in the best end of life option (re-use, re-manufacturing or recycling). Implementing this tool, the framework will be completed, enabling a full lifecycle improvement of manufacturing systems.

About lifecycle, it is necessary to consider also the social pillar, which is arising during the last years. Social Life Cycle Assessment (S-LCA) methodology will be therefore studied, in order to understand if it is possible to add social evaluation to economic and environmental ones.

About environmental impact, instead, it is necessary to understand the impact categories to take into account. It is important to conduct a literature analysis or a survey to collect the main impact categories related to manufacturing systems.

Finally, Closed Loop Framework needs to be tested in the industrial context. Now, it is applied in a company that produce manufacturing systems for the automotive sector, and at the end of the application a first evaluation will be conducted. The goal is to involve other industrial companies, in order to refine and validate the framework.

References

1. Terzi, S., Panetto, H., Morel, G. and Garetti, M. (2007). A holonic metamodel for product traceability in PLM. Int. J. Product Lifecycle Management, Vol. 2, No. 3, pp.253–289.
2. IFIP-IPAC Task Force, GERAM Generalised Enterprise Reference Architecture and Methodology, Version 1.6.1, 1998
3. Society of Automotive Engineers (SAE). Reliability and Maintainability: Guideline for Manufacturing Machinery and Equipment. 1999, available from M-110.2, Warrendale, PA
4. Scientific Applications International Corporation (SAIC). Life Cycle Assessment: Principles and Practice. 2006, available from 11251 Roger Bacon Drive, Reston, VA 20190
5. Cerri, D., Taisch, M., Terzi, S. (2013) 'Proposal of a multi-objective optimisation of product life cycle costs and environmental impacts', International Journal of Product Lifecycle Management, Vol. 6 (4), pp. 381-401
6. Cocco, M., Cerri, D., Taisch, M., Terzi, S. (2014) 'Development and implementation of a Product Life Cycle Optimization model', Proceedings of 2014 International Conference on Engineering, Technology and Innovation (ICE), Bergamo, Italy