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Abstract. The paper describes a possible but concrete implementation pattern that is currently used to introduce and apply a sustainability-centered strategy in a mould&die company (INTERROLL SA). Focus of the analysis, implementation requirements, designed procedures and a draft software architecture are here outlined, forming the conceptual basis for a value-adding and easily adoptable approach intended to promote the implementation of a so widely-speculated strategic theory. The described path could be easily adapted to other mould&die companies and further extended to different industrial sectors.

1 Introduction

Most innovative manufacturing companies are today exploring **sustainability-related strategies** as a guide to re-design their business processes, either motivated by end customers' increased pressure towards environmentally- and socially- compliant products and processes [7] or, less virtuously, interested in catching the latest marketing wave. In both cases, such prospective adopters are looking for actual implementation examples and practical procedures to follow in order to become "sustainable" or "more sustainable" (than before or than the competitors). Unfortunately, a **formalized approach** supporting sustainability strategy implementation is still missing (some examples are available but focusing on mere environmental parameters or with limited applicability [8]): which are the steps a potential sustainable entrepreneur has to follow? Which are the available tools he can adopt? Which product/company lifecycle phases are more appropriate for starting such a path? A practical, experimented and industrial-oriented sustainability implementation procedure has been never described in literature (apart from [2], where authors propose an *exercise* addressing a wooden furniture): lack of descriptive capabilities or lack of actual examples?

According to literature [10, 12], one of the major problems with sustainability-centred business models relates to the simultaneous pursuit of private (companies' and customers') and public (society and environment) benefits. As long as public benefits don't result into countable private advantages, more sustainable production systems and products may be competitively disadvantaged. From here it comes the first pre-requisite for sustainability strategies implementation: the availability of **metrics**. Metrics enable the *measurement* of sustainability and, specifically, of private (and, incidentally, public) benefits. Measuring allows comparison, thus enables decision-making. Many international initiatives have developed indicator sets, formulae and recommendations for this purpose, even if rarely addressing specific requirements of manufacturing environments. Authors coordinated and successfully completed an FP7 research project[1] addressing this specific purpose: now a set of manufacturing-focused metrics has been consolidated and validated in real production contexts [1].

Being metrics an (almost) achieved pre-requisite, target identification is the second required step. The selection of a proper business case is fundamental to provide a value-adding, extensible and comprehensive analysis for future adopters. Manufacturing environments more likely adopting sustainability-enhancing practices are those where private and public benefits are (both) virtually significant. This happens in industries: (i) with a relevant impact on at least one of the sustainability spheres, (ii) with large room for improvements, (iii) witnessing relevant pressure from important stakeholders on sustainability-related themes, (iv) facing cost-based competition from low environmentally- and socially- sensitive countries.

Injection moulding is the most important commercial method of plastics processing. It is used to mass-produce components fast and with little or no finishing operations. Nearly all markets use injection moulded plastics (from packaging to building). The interaction with final customers is thus continuous and, sooner rather than later, there will be standards for carbon footprints or social friendliness in injection-moulded products manufacturing (point (iii)).

AMI [6] estimates that there are approximately 16,500 injection-moulding sites in West and Central Europe operating over 220,000 machines. This makes mould&die numerically relevant. The environmental profile of injection moulding has demonstrated its great impact: the overall injection moulding energy consumption in the U.S. in a yearly basis amounts to 2.06×10^8 GJ [11], similar to the energy consumption of some developed countries (see points (i) and (ii) above).

In a 2010 report entitled *The Future of the European Injection Moulding Industry*, AMI observes that the European injection moulding industry faces weakness in demand across a range of end use sectors, with customers looking to reduce the price of components, while raw material and energy costs rise. This favours producers willing and able to relocate to lower-cost manufacturing sites out of Europe. As a result, the number of moulders operating in Europe have fallen by 9% over the past six years. European injection moulders are asked to identify a radically different competitive framework, and sustainability-focussed strategies are a really attractive chance to proactively reposition their business and capitalize on the environmental gaps of their operations, also considering the available options of performances improvements enabled by appropriate mould design [4], careful material selection [9] or adopted manufacturing technology.

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[1] FoF.NMP.2010-2 – Sustainable Mass Customization, Mass Customization for Sustainability

Exploiting preliminary results of the Swiss research project SAM (see § 6), promoted by SUPSI and INTERROLL SA, in this paper, authors are not meant to present and revise the state of the art of sustainability evaluation, but would like to describe their current experience in implementing sustainability assessment and advisory in a mould&die company. Preliminary decisions concerning the target of the analysis are discussed in § 2, while § 3 presents the specific requirements for sustainability adoption in the mould&die context. The designed solutions are conceptually presented in § 4, where the SAM platform architecture is formally described. Considerations on the achieved results and planned next steps are finally presented in § 5.

2 The Focus of the Sustainability Assessment

In conformity with the methodology of Life Cycle Assessment (LCA) [5], the focus of the analysis has to be identified before a sustainability assessment is performed.

In mould&die industry, both the mould and the moulded product can be considered as the subject of the sustainability assessment, depending on the focus companies are more interested in. Within this industrial sector, companies activities and products are highly diversified ranging from (i) companies that directly design and produce the moulds and (sometimes) sell the moulded product as components for other final products, to (ii) enterprises that directly produce and commercialize the moulded plastic parts as final product, so moulds are not necessarily designed and realized by the company itself. The first group of companies seems to be more focused on the mould sustainability analysis, whereas the second group is more interested in calculating the sustainability level of the moulded products. In this perspective INTERROLL could be classified into the first group, but in order to confirm the common sense suggestion, the INTERROLL mould and moulded product lifecycles have been analysed.

2.1 The INTERROLL Mould and the Moulded Product Lifecycles

Lifecycle perspective is considered a *must* in the evaluation of the environmental, economic and social performances of a product [1]. Considering the mould and moulded product lifecycle, the following steps can be described. The *Extraction* takes into account the extraction of metal ore for the mould production, while the extraction of petrol for moulded part realization. *Material processing* considers the millwork of mould metals components and the transformation of the polymer in granules for the moulded product. In *Part manufacturing* metal milling is considered in mould production, while injection moulding for moulded parts. In *Assembly* the junction of mould components (e.g. plates) are considered for the mould. Starting form *Assembly*, the lifecycle of the moulded product is intimately related to those of the final product the plastic component belongs to. In the case of INTERROLL, *Assembly* includes the insertion of the plastic parts within the conveyor roller. The *Use* phase of the mould, injection moulding, corresponds to the manufacturing of the moulded product. Whereas, the use phase of moulded products coincide to the conveyor roller functioning. Mould *Maintenance* includes the substitution of some mould parts. In the case of the moulded part, *Maintenance* has to be evaluated within the conveyor roller repairing. The *End of life* of the mould is well known by INTERROLL, while it has many uncertainties for the moulded product since the conveyor roller could face different end of life scenarios in different countries. Eventually, the *Transportation* phase concerns the transportation of the mould components and the distribution of the moulded products. The description of the mould and the moulded product lifecycles of INTERROLL ease the definition of the focus of the sustainability assessment.

2.2 Analysis Focus

The lifecycles description allows to identify all the lifecycle activities directly managed by INTERROLL and that are affected by the decision taken by the company.

Focusing on the mould, all the processes performed during lifecycle are either carried out or influenced by INTERROLL and decisions performed in mould design directly affect the sustainability performances of the mould. Extraction and material processing are influenced by mould design since the materials constituting the mould are here selected. Manufacturing and assembly processes are the results of design decisions. The use of the mould is the injection process, so it is the meeting point between the mould and the moulded product. In this phase, some elements as the energy consumed or the plastic wasted are actually affected by mould design; others are related to moulded product design as the quantity of the material injected. Eventually, also maintenance, End of Life and transportations are directly influenced by decisions performed during the supply chain configuration.

Analysing the moulded product lifecycle, it is possible to note that INTERROLL design decisions address the extraction, the material processing, the manufacturing phase and the upstream transportation. On the contrary, the company has a scarce control on the assembly, use, maintenance, end of life and downstream transportation phases since the moulded product is a part of a more complex product, i.e. the roller conveyor. In this perspective, choosing the mould as the focus of the sustainability analysis, INTERROLL is able to directly influence the environmental, economic and social impacts of the mould. Moreover, this approach allows to model and include into the analysis the impacts of the moulded product.

3 The Mould&Die Requirements in Sustainability Assessment

As mentioned in § 1, marketing and labelling is neither the only, nor the main goal of SAM, since the conceptualized tool/procedure is meant to promote awareness creation of both designers and managers, and guide them towards a more sustainable way to handle their products. In this chapter, requirements gathered and worked out in the preliminary steps of the project are presented and discussed.

What's the object to assess?

As discussed in § 2, the mould is the focus of the sustainability assessment, both targeting already existing and new moulds that have to be designed.

Which are the assessment dimensions?

The sustainability assessment has to be performed through the calculation of appropriate indicators. The process of identifying and selecting these indicators constitute a background for this work [1]. The use of numbers enables assessors to objectively evaluate the sustainability level of mould allowing to determine a benchmark and compare alternatives. Moreover, the chosen assessing dimensions have to be holistic from three complementary points of view, considering: (i) all the three sustainability areas (environment, economy and society); (ii) the product, the process and the supply chain; (iii) the lifecycle approach. This entails the need to get information of phases carried out by other actors and integrating them into a unique system.

Which are the needed data?

Data required for sustainability assessment can be grouped into three sets: (i) product-specific data, that need to be filled from time to time by the designer or the technician. These are morphological, technical and operational data strictly related to the given product and production process; (ii) company-specific data, related to the company and to its supply chain, and that can be updated on a longer time basis (e.g. when a new supplier joins the supply chain); (iii) general-knowledge data, usually coming from third-party databases (e.g.: Ecoinvent – www.ecoinvent.ch).

Who's the assessor? When are they performing the assessment?

Assessors are all the decision makers having some sort of power over the sustainability performances of the assessed object. Here two are the most relevant *users*: technical profiles (i.e.: mould designers) and managerial profiles. The first group is usually well alphabetized on the use of design software, but has no expertise on sustainability issues. Managerial profiles are usually not keen to handle shop-floor data and complex design software: they need a high-level management platform enabling comparison and storage of data intended for tactical to strategic decision support.

Two requirements are connected with the "timing". According to [3], assessors are expected to act both ex-ante, during the design phase and ex-post, for *pure* assessment purposes. The analysed object is respectively the design of future moulds or existing moulds. The sustainability level of new moulds has to be measured in real time during the design phase in order to drive designers' choices. The sustainability level of already used moulds have to be measured for benchmarking and product labelling.

What's the envisaged response?

In general it is not possible to define "the sustainable product", but a "more sustainable product" compared to a benchmark. The array of indicators values concerning different mould configurations calculated by the platform is a valuable information for designers that are thus aware of the design decision effects on sustainability impact, and are driven in identifying an improvement path. The platform has to enable decision makers to identify a benchmark or select product concepts already assessed. In this perspective, this diagnostic feature would enable an iterative design path aiming to enhance the mould sustainability performances while designing. Finally, the analysis of sustainability impacts has to be carried out at different levels of detail. The final values of indicators provide an aggregate picture of how well the designed mould performs. This could be analysed through the above-mentioned comparison between two or more product configurations or "zooming" on a single indicator value or to given steps of the lifecycle or of the solution space.

4 The Solution Concept

In order to properly satisfy the requirements for the sustainability assessment of a mould, and considering the focus of the evaluation, a possible solution to implement the analysis of the environmental, economic and social performances is here drafted.

This solution is thought to be implemented via a software tool since a huge amount of data has to be gathered and managed and many calculations are required. In this perspective the design of the solution is presented through the Component diagram depicted in **Fig. 1** obtained using the UML 2.0 notation. Two main macro-blocks could be identified, such as the front-end block and the back-end block.

The front-end block handles the interaction with the user and it is practically constituted by the Company Editor, the Mould Editor and the Diagnosis tool. The Company Editor encapsulates all GUI and logics that interact with the company-level data representation. Therefore, it's used to edit the information characterizing the company and its suppliers (e.g. the number of injuries, the sales turnover…), information that are needed for the sustainability assessment but that have not to be edited or added for each new SAM project. The *Mould Editor* contains GUI and logics used for the description of the mould in analysis. The *Mould Editor* component is indeed supported by the Diagrams Module that provides tree diagrams edit functionalities used for bill of material representation. It provides a specific live data model representing tree diagrams and their editing modelling, and undo/redo functionalities implemented as memento pattern. It also delivers graphical representation of the editing process. Answering to the management requirements, the *Diagnosis Tool* encloses GUI and mechanics used for browsing, analyse and compare sustainability assessment of various moulds and mould families.

The back-end block is meant to expose a series of services that are crucial for the calculation of the indicators values such as the *Core*, the *Engine Block* and the *Importer*. The *Core* module is thought to be the repository of the main live data model of the SAM platform and is responsible for its management, ensuring the continuous consistency of data. It also provides listening capabilities for other modules, enabling them to have a targeted reaction to every update of the model state. Moreover the core module provides generic GUI functionality to directly interact with the underlying data representation. The *Engine Block* is indeed constituted by the *Assessment Service*, the *Simulation Service* and the *Maintenance Classifier*. The *Assessment Service* module enables the sustainability assessment impacts computation. It will rely on specific live data model and a computational engine that is meant to calculate a defined set of sustainability indicators. The *Simulation Service* and the *Maintenance Classifier* modules have an important role for the indicators calculation performed during the design phase of the mould since they are meant to provide designer with forecasted data concerning the use and the maintenance phases.

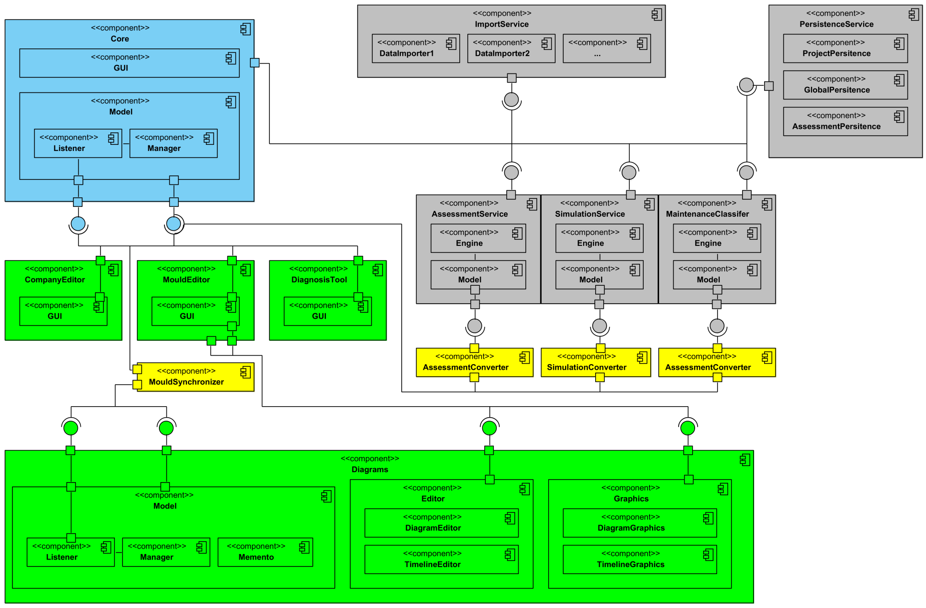

Fig. 1. Component diagram of the solution concept

The *Simulation Service* provides simulation capabilities in order to predict energy consumption and other critical parameters for the detailed characterization of the injection moulding process. The *Maintenance Classifier* provides expert system functionalities to predict the required maintenance effort for different moulds. The *Importer* module contains data import functionalities that are registered in the application in order to allow the user to import various types of external data to facilitate the data entry process. This component thus represents the connection with the IT system already existing in INTERROLL (e.g. CAD, ERP…). The sustainability assessment in fact requires a certain variety of data concerning the product, the manufacturing system and the supply chain [3] thus many data sources are needed.

5 Conclusions

Preliminary results achieved in implementing sustainability assessment and advisory in a mould&die company are here presented with the goal to provide prospective sustainability-conscious entrepreneurs with a practical path to follow when moving their business towards a more sustainable profile. Achieved results contemplate the focus of the sustainability analysis definition, requirements gathering and identification of a possible solution that could be easily translated into software platform conceptual architecture. Further steps are mandatory (and planned) addressing the final development and validation of the software platform, data collection and sustainability benefits measurement of the project, for both private and public audience. Since most of the requirements identified in § 3 have a general-purpose attitude, the approach and the solution here outlined could be easily adapted to other mould&die companies and further extended to different industrial sectors.

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