# MANUFACTURING COST ESTIMATION DURING EARLY PHASES OF MACHINE DESIGN

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## ABSTRACT
Machine design process requires the effective and rapid assessment of different design solutions. Beyond functions and technical performance other parameters as safety, manufacturability, assemblability etc. have to be taken into account. Manufacturing cost is one of the main factors in order to choose the most suitable solution, so accurate estimation in the early design phases is fundamental. Design to cost implies to manage a vast amount of manufacturing knowledge that has to be linked to the design parameters. Feature based 3D CAD models contain data useful for cost estimation but, despite the numerous researches on features recognition and extraction, no cost estimation software system yet assures reliable results. In such context, this paper presents an approach for rapid manufacturing cost estimation where design features are automatically linked to manufacturing operations. The approach has been implemented into a knowledge-based system and tested on practical case studies in order to validate the performance.

*Keywords: Design to cost, Feature-based costing, Manufacturing features, Knowledge-based system*

## 1 INTRODUCTION

Market globalization drastically increased competitiveness. Customers ever more have the possibility to choose products by evaluating a large number of market proposals. In this context, if a company is able to offer high quality customized products in a reasonable delivery time can gain relevant market shares. Anyway personalised products imply new efficient and agile approaches along the whole product development process, from ideation to manufacturing. In this scenario, companies have to apply methods and tools in order to respond to the customer needs while maintain a constant control on product cost. Manufacturing cost is one of the main important aspects. It should be evaluated in the early design phases in order to rapidly compare different customized technical solutions.

Manufacturing cost estimation is complex due to the huge amount of information that influences the result. In fact, it is necessary to decide which manufacturing process should be adopted, which manufacturing parameters should be chosen, which materials, which equipments have to be realized, the size of production lot, etc. On the other hand, the product designer in the early design phase has at disposal only a preliminary 3D CAD model that has been mainly conceived in order to satisfy the functional requirements. This dichotomy generates errors and numerous iterations between design and manufacturing departments. A consistent improvement can be achieved if product designer can evaluate different design alternatives by using criteria related not only to function but also to manufacturability and cost. In order to overcome this problem, manufacturing knowledge should be shared across the company and used as one of the drivers of product design.

The idea of the present approach is to provide designers with a Knowledge-Based (KB) tool that analyzes the product design information by using a manufacturing knowledge base in order to automatically obtain the estimation of manufacturing cost.

The 3D feature-based CAD model contains the product structure that is concretized through geometrical features, components, assemblies, and not geometrical data (roughness, tolerances, material, etc.). The knowledge-based tool analyzes the CAD data structure and extracts the design information it needs. Manufacturing and process planning rules are collected in the knowledge base. The manufacturing operations are automatically linked to the design features. In order to make this combination in a robust way new clusters of data, called *advanced manufacturing features* and *simple modelling features*, are defined. Finally, after design and manufacturing features mapping, the system generates the cost estimation.

Currently, the developed software tool manages the main mechanical manufacturing operations from machining to welding. Starting from the shared knowledge base it has been conceived to be used in different company departments: the design department, the product-engineering department and the purchasing department. The tool is under test in collaboration with a company that realizes woodworking machines.

## 2 RELATED WORKS

The Design for Cost (DfC) methodologies have been studied and formalised since 1985 [1]. The DfC problem can be resumed in the following way: studying and developing methods and tools allowing the designer to calculate costs in the early design phase by managing the knowledge of the production processes and, hence, the costs incurred therein [2]. Many CAPP (Computer Aided Process Planning) systems have been developed during the last years but they are too complex to be used in the design phase because they require a lot of information beyond the product characteristics and they are, generally, not available during the first stages of design process.
A large number of approaches and methods for cost estimation have been presented in literature [3]. An interesting classification has been reported by Duverlie and Castelain [4]. In Niazi et al. [5] a detailed review of the state of the art in product cost estimation covering qualitative and quantitative techniques and methodologies are described. The qualitative techniques are further subdivided into intuitive and analogical, and the quantitative ones into parametric and analytical. A recent review concerning the cost estimation software systems usable during the product development process is reported in Cheung et al. [6].
According to Weusting et al. [7] cost estimation can be divided into two basic methodologies: generative cost estimation and variant based cost estimation. In the first case, the estimate is based on the decomposition of costs related to the expected production processes. In the second case, the analysis of similar past products allows the evaluation of new ones. It can be stated that a suitable cost estimation tool should include a combination of these two approaches. Feature-based costing [8] can be considered an optimal compromise between them. In fact, features can be used in order to describe the geometric information of product at different levels of detail, and they can be used to collect all functional and technological information (tolerances, surface finishing, manufacturing cycle, etc.). Yet, features defined in a previous product can be reused for the new solutions inheriting all process information. Parametric feature-based 3D CAD modeling systems can provide the practical support to manage the cost information along with the functional product definition and its virtual representation. Several feature-based costing technology applications are reported in scientific literature, an overview is provided in Layer et al. [9]. For example, in Ten Brinke [10] an interesting system for estimating costs of sheet metal components is described. However, there exists no satisfactory computer-aided support for the cost estimation task related to all manufacturing operations domain. Important research works have been carried out in machining operations [11-12], but the developed systems are not well integrated in the design process flow. An approach where cost estimation has been applied during design phase is reported in Germani et al. [13]. The work shows how a cost estimation method can be used effectively within a framework in order to manage the configuration of a product variant. Other interesting cost estimation supporting systems usable in the early design phases are described in Shehab and Abdalla [14], Liu et al. [15] and Mauchand et al., [16].
The proposed system overcomes the state of art by developing a robust KB system able to support the product development process in the most critical phases by providing the right level of detail of manufacturing cost information.

## 3 APPROACH

During a generic product development process, mainly three company departments are involved in product costing. Firstly, product design department where product cost is created by adopting specific technical solutions. Secondly, product engineering department where product feasibility is studied, manufacturing operations are defined and, thus, detailed cost is calculated. Finally, the purchasing department that interacts with the supply chain in order to establish prices and choose the best suppliers.
Engineers of these three departments interact with product cost from different viewpoints. Product designers need to understand the incidence of a single cost feature on the total manufacturing cost without a specific skill on manufacturing operations during the design phase. Product engineers (or

manufacturing technologists) possess the specific knowledge about the manufacturing activities necessary to determine the detailed cost. Purchasing staff is interested to the cost calculated by the product engineers, in order to select the supplier for every component.
The proposed approach originates from the concept that above departments base their activity on a shared cost model and a related cost estimation tool. This idea leads to the cost process formalization, through a specific cost estimation software tool, able to work on a detailed cost model defined by users (designers, production technologists and buyers) using customized interfaces. Such software is a step beyond than current systems commonly used within companies to evaluate the manufacturing costs.
In this way are avoided problems due to a scarce awareness of designers to the cost problem, shifting toward the product engineers all cost evaluation activities. Such a situation implies errors and, consequently, numerous and time-consuming iterations. The approach is schematised in figure 1where a single software cost estimation tool is used in the three main phases. This work aims to overcome the problem by developing a software tool dedicated to the design department but also providing a specific view of the product cost model for the other two user typologies (figure 1). A shared manufacturing knowledge base is used as key element in order to define this multilevel framework.

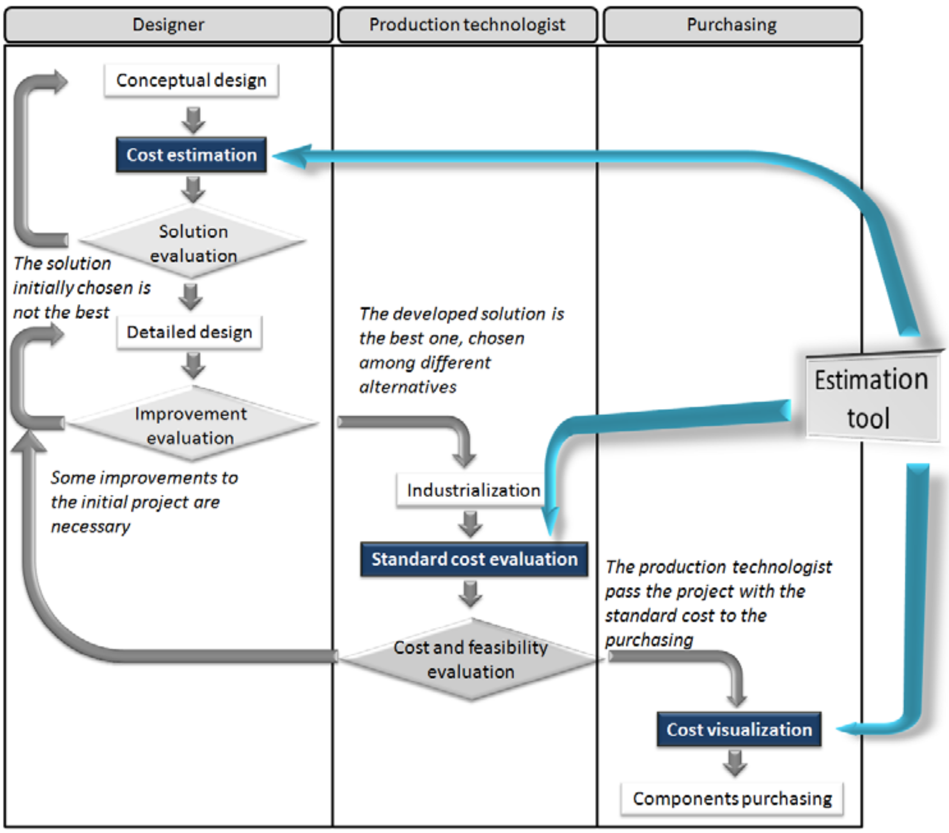


*Figure 1. Cost estimation process related to the three different departments*

In order to make usable this framework to all users, it is necessary to develop a detailed estimation method aimed to satisfy the deepest user, who is the product engineer.
Estimation methods can be classified in four typologies: intuitive, analogical, parametric and analytical. Among them, the most coherent with the proposed objective is the analytical method. In fact, it allows evaluating the product cost by the decomposition of work required into elementary activities (an example of an elementary activity is a machine tool operation).
At the design stage, by using the analytical approach it is necessary to determine all activities needed for component/assembly manufacturing. While product engineers have experience for cost estimation, the designer rarely has the same kind of knowledge. Hence, it is essential to formalise the manufacturing knowledge in order to apply it during the early cost evaluation.
Manufacturing cost is defined by 4 cost items: three of them are variable (they don’t depend by the production lot dimensions (they are specific for a single component), while one is fixed (it’s a cost to setting up machines). In detail, cost items are the following:

- *Machining cost*: time during that the machine works the piece, multiplied by machine unitary cost;

- *Stock cost*: stock weight required to manufacture final product multiplied by stock unitary cost;
- *Accessory cost*: time during that the machine doesn't work the piece, because, for instance, it is changing tool or piece, multiplied by machine unitary cost;
- *Machine set up cost*: time during that the machine is performing activities at the beginning of a lot production, such as CNC program testing, tool setting up, etc., multiplied by machine unitary cost.

The product engineer knowledge has been structured in order to support the analysis of product design information and translate it in manufacturing operations and, hence, in manufacturing cost.

Manufacturing technologies have been analyzed and divided into classes as follows: chip-forming machining, mechanical carpentry, painting, thermal treatments, superficial covering, metallic alloy molding and plastic molding. Classes have been further divided into categories, for example the machining class has been subdivided in milling, turning, grinding, gear cutting, broaching and slotting. Within these category have been defined the operations, for example typical operations for milling are face milling, slot execution, etc. Then, the geometrical parameters have been determined in order to univocally characterize the operations. For example the face milling operation is characterized by length, width, depth, geometrical tolerance (planarity) and roughness.

In the proposed knowledge base, the operation is the most important level of data aggregation.

The operations have been univocally mapped with a specific set of geometric and non-geometric elements that have been defined *advanced manufacturing features*. In this way the product model can be represented as a collection of advanced manufacturing features and simple modelling features. The recognition of these features on the product model allows establishing the operations and their sequence.

In more detail *advanced manufacturing features* are a set of geometrical elements (faces and axis) conveniently arranged in a recognisable topological shape with specific dimensional constraints and with specific manufacturing information (tolerance and roughness). This information determines a group that can be associated to a specific operation. The advanced manufacturing features have been defined because it is not always possible link the CAD modelling feature to a machining operation. In many cases, in fact, in order to manufacture a feature it could be necessary more than one operation, otherwise more features could be machined with a single operation. This problem is typical for the chip forming machining, where different ways could be adopted in order to realize a component. In the following table (table 1) examples of advanced manufacturing features are reported.

*Table 1. Examples of advanced manufacturing features.*

| **Advanced Manufacturing Feature** | **Definition** |
|---|---|
| External cylindrical slot | External cylindrical surface enclosed by surfaces with a diameter greater than reference one, and the cylinder length is greater than 6 mm., furthermore it should be guaranteed the radial accessibility of the tool |
| External cylindrical turning | External cylindrical surface which does not have any faces with a radial range greater than the machining surface diameter, moving from the machining surface to the tailstock, furthermore it should be guaranteed the radial accessibility of the tool. |
| Frontal slot | Planar surface enclosed by cylindrical surfaces (one external and the other internal) in order to form a solid angle greater than $\pi$. It should be guaranteed the axial accessibility of the tool. |

In other cases the simple CAD modelling features can be directly linked to the operation; for instance the thread hole definition as represented in the CAD model data structure is sufficient to determine the corresponding operation.

The second knowledge level is oriented to the determination of manufacturing cost, starting from the operations list with their geometrical parameters. This level is based on the definition of algorithms that the product engineer uses in order to determine all technological parameters necessary for cost estimation process. These algorithms need a lot of data (raw material cost, standard equipment time, etc...) and relations (material-cutting speed, material,-machine-tool-feeding rate, welding speed-bead dimension-material, etc...) that can be stored within a technological database. The values extracted from the database are elaborated by specific formulas used to calculate the estimation parameters and the final component cost. Typical formulas, within the metal working machines field, are those used for the calculation of tool paths length, working time, cost, etc.

In order to understand how the proposed approach is able to estimate the manufacturing cost a simple example is reported. It interests the external cylindrical slot advanced manufacturing feature (figure 2). The taxonomic definition of this feature is reported in table 1.

The data structure of the 3D CAD model is analyzed and proper algorithms compare the definition of external cylindrical slot feature with the geometric model in order to recognize it with its geometrical parameters (on the basis of classification as in table 1): initial diameter (Di), final diameter (Df), radial allowance (P), slot length (L) and roughness (R).

Once the geometry has been identified it is possible to determine all activities necessary for slot execution. In this case by using a rule based on the roughness value can be chosen the needed activities and the machines tools for machining:

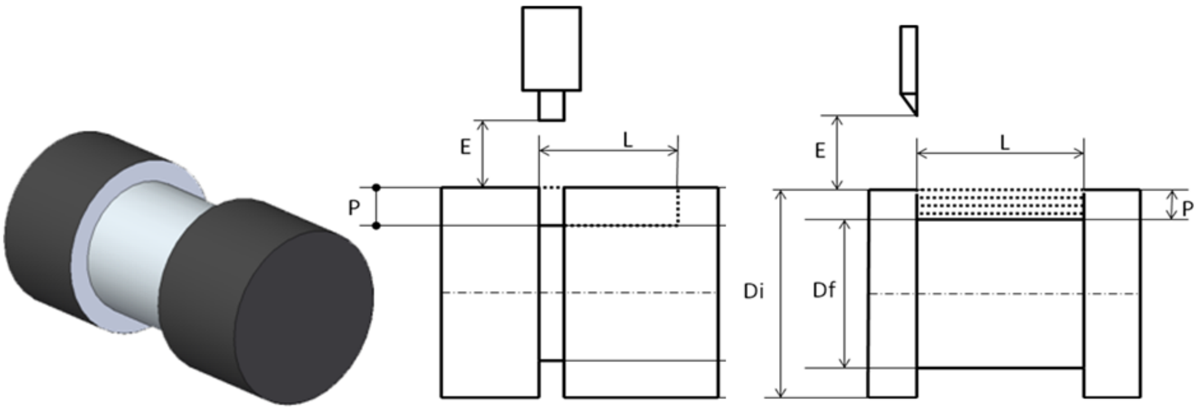


*Figure 2. On the left, the grey faces represent the external cylindrical slot. In the centre and right the first and second phases of the turning operation are respectively shown.*

| | | | |
|---|---|---|---|
| **IF** | $R \leq 0.8\ \mu m$ | **THEN** | *turning (roughing and finishing) + grinding* |
| **IF** | $0,8 < R \leq 3,2$ | **THEN** | *turning (roughing and finishing)* |
| **IF** | $R > 3,2\ \mu m$ | **THEN** | *turning (roughing)* |

Hence, the necessary phases for slot realization are: the execution of the initial relief and the external cylindrical turning. Taking into account only the second phase, the formulas used in order to calculate the machining time are as follows:

*Roughing passes* $NPs = \frac{P}{Pp}$ (1)

*Medium diameter* $Dm = \frac{Di + Df}{2}$ (2)

*Rotational speed* $n = \frac{1000 \cdot Vc}{\pi \cdot Dm}$ (3)

*Roughing feeding rate* $VAs = n \cdot As$ (4)

*Finishing feeding rate* $VAf = n \cdot Af$ (5)

*Working time* $Time = \left( \frac{L + E}{VAs} \cdot NPs \right) \cdot 1.25 + \left( \frac{L + P + E}{VAf} \cdot NPf \right) \cdot 1.25$ (6)

Where Pp is the cutting depth, Vc the cutting speed, As the roughing feed, Af the finishing feed, NPf the pass number for finishing, E the extra traverse and 1,25 is used to consider the rapid traverse.

The machine tool is chosen using other rules. In case of a bender, for instance, machine and number or workers are chosen according to the sheet metal weight, and bends length. Following, some rules for bender choosing:

**IF** *Lmax > 4000* **THEN** *bender L>4000 + 2 workers* (7)

**IF** $3000 < Lmax \leq 4000$ **OR** $P \geq 12$ **THEN** *bender L≤4000 + 2 workers* (8)

**IF** $0 < Lmax \leq 3000$ **OR** $P < 12$ **THEN** *bender L≤4000 + 1 worker* (9)

Once machine has been identified, machining cost is calculated multiplying time by machine unitary cost. Analyzing the working schedule, LeanCost calculates the list of tools, the number of grips, part dimensions and overall, parameters used to define set-up and accessory costs. Stock cost depends by stock category (sheet metal, beam or die), final part weight and geometry.

In a similar way is performed the welded assembly cost estimation; in this case first of all each component is separately evaluated and their sum represents the assembly stock cost. Later, once the assembly manufacturing features have been defined (welding, machining, painting, etc.), machining, accessory, and machine set-up costs are evaluated as well as the final cost.

## 4 LEANCOST: MANUFACTURING COST ESTIMATION SYSTEM

The described approach has been implemented in a software tool called "LeanCost". In figure 3 is represented the system structure.

This tool is a Windows-based application that currently can estimate the cost of components and welded assemblies. In particular it has been implemented taking into account the context of companies where Product Lifecycle Management (PLM) systems are present. PLM system contains engineering data such as CAD models, drawings and documents stored in the PLM database. LeanCost interacts with the PLM system in order to extract the needed geometric (*CAD models and drawings*) and non-geometric information (*material and other metada such as weight, status, description etc.*). LeanCost provides also specific interfaces with PLM systems (till now only one interface has been managed), used also to synchronize data between LeanCost database ad PLM. Examples are represented by the materials (*code, description, density, unitary cost, workability factor*) , sheets metal (*code, description, status, material, thickness* and *unitary cost*), beams (code, *description, material, status, section, type* and *unitary cost*) and dies tables (*code, description, material, weight* and *unitary cost*). Data synchronization allow LeanCost to use always updated data.

The structure includes also specific databases about machine tools, materials and cutting parameters (cutting speed, setup time, etc.).

The LeanCost application supports three different user access levels:

- **Designer user**: the access is integrated within the CAD system user interface; the system performs automatically the cost analysis. As output he/she examines a cost report that highlights the different cost drivers. In this way the system suggests which factors should be changed.
- **Technologist user**: he/she inherits the cost analysis from the design phase; this user verifies the results and analyses various reports in order to plan the manufacturing activities. The technologist user can set the process and working cycle parameters.
- **Purchase department user**: this access level is limited to the cost reports; they are used to choose the most suitable suppliers.

As shown in figure 3 the LeanCost tool is composed of four main modules:

- **CAD Interface Module**: this module, that is developed using Visual Basic.NET programming language, analyses the CAD model and the related not geometrical information in order to identify the advanced manufacturing features. This module is linked to the PLM system (in this research is used Solid Edge.20, by Siemens Gmbh). The extraction of information from the CAD model is made by reliable classes and functions properly developed. They perform a topological analysis of all geometrical entities. The module generates as output an ordered set of advanced manufacturing features represented through geometrical entities (faces, loops, edges), dimensions, finishing, tolerances and physical properties (mass and density). This module identifies also the simple modelling features.
- **Process Allocation Module**: the set of ordered advanced manufacturing features and simple modelling features are converted in a set of operations using this module. Then all geometrical and physical data are elaborated in order to determine each manufacturing process. This tool establishes the necessary processes to manufacture the component, and it proposes possible machines tools with their cutting parameters. This module interacts with external databases that store machine tools, materials and cutting parameters.
- **Calculation Engine**: a stand-alone module calculates the manufacturing time by using proper computation functions related to the different processes. Then it translates the manufacturing

time in product cost.

- **Report Generation Module**: it manages all calculated data and processed by the other tools.

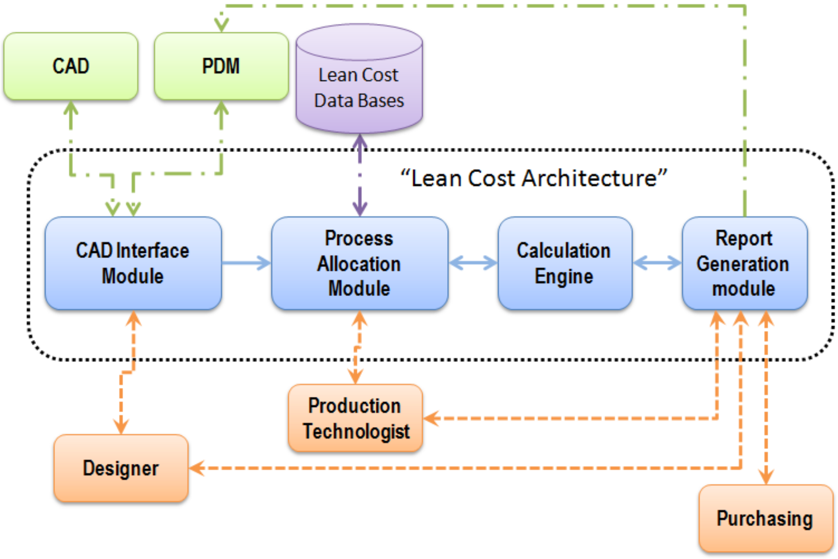


*Figure 3. LeanCost system structure*

The different user interfaces are reported in figure 5.

A typical cost estimation work session implies the following stages. The designer works on the project for each product model (component or assembly). He uses the CAD system and generates the product cost estimation by using LeanCost. By analyzing the cost of different solutions, the designer can identify the best one. The cost estimation activity done by designer follows predefined wizards (axisymmetric, prismatic, sheet metal, beam and cogwheel parts or assemblies), constituted by a set of steps. They are the following:

- *Model reading and verification*: LeanCost check is 3d model has all the pre-requisites it needs, such as material, a general roughness value, a valid flattening (in case of sheet metal), etc.. In this phase the user checks these requirements and solve them through CAD system;
- *Stock calculation*: automatic algorithms are able to define the optimum stock (stock smallest as possible, fitting material, type, as section, and state). User can choose a different stock, even if software check if new selection is feasible;
- *Grips definition*: automatic algorithms are able to calculate how many grips are required for the part machining, even if user can check and change them;
- *Manufacturing feature calculation*: feature recognition algorithms allow the advanced manufacturing feature calculation, reading 3d geometry. A default technology is defined for each feature (for instance a cut on a sheet metal can be done using laser, oxyacetylene torch, punching or nibbling), even if user can change it, according to lot dimension, production planning (in case he knows it). This step is made of other sub-steps, with the aim to better group feasible features for a specific kind of components. For axisymmetric components, for instance, has been defined 25 features, grouped in cylindrical, frontal, conical and integrated operations plus slots, grooves and holes;
- *Cost summary*: a final report is presented to user, in order to show each cost item with relative impact on total cost.

The created project is stored into a shared database, so the technologist can retrieve it. This user works on project elaborated by the designer in order to refine the estimated cost and modify, if necessary, the cost of specific processes. The calculated cost with notes related to the feasibility or improvements can be sent back to the designer (Figure 4). LeanCost is able to trace the communication between the design and product engineering departments. When this iterative process is completed the project is released. The released project by the manufacturing technologist, then, is ready to be sent to the purchasing department, for the supplier selection.

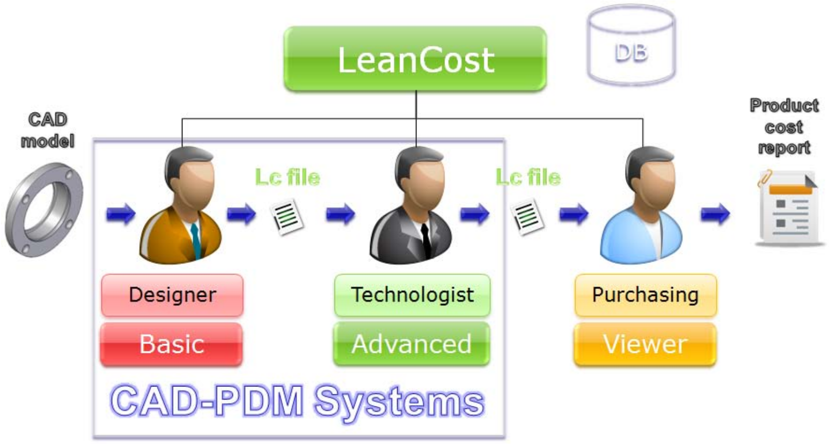


*Figure 4. LeanCost interfaces and cost evolution*

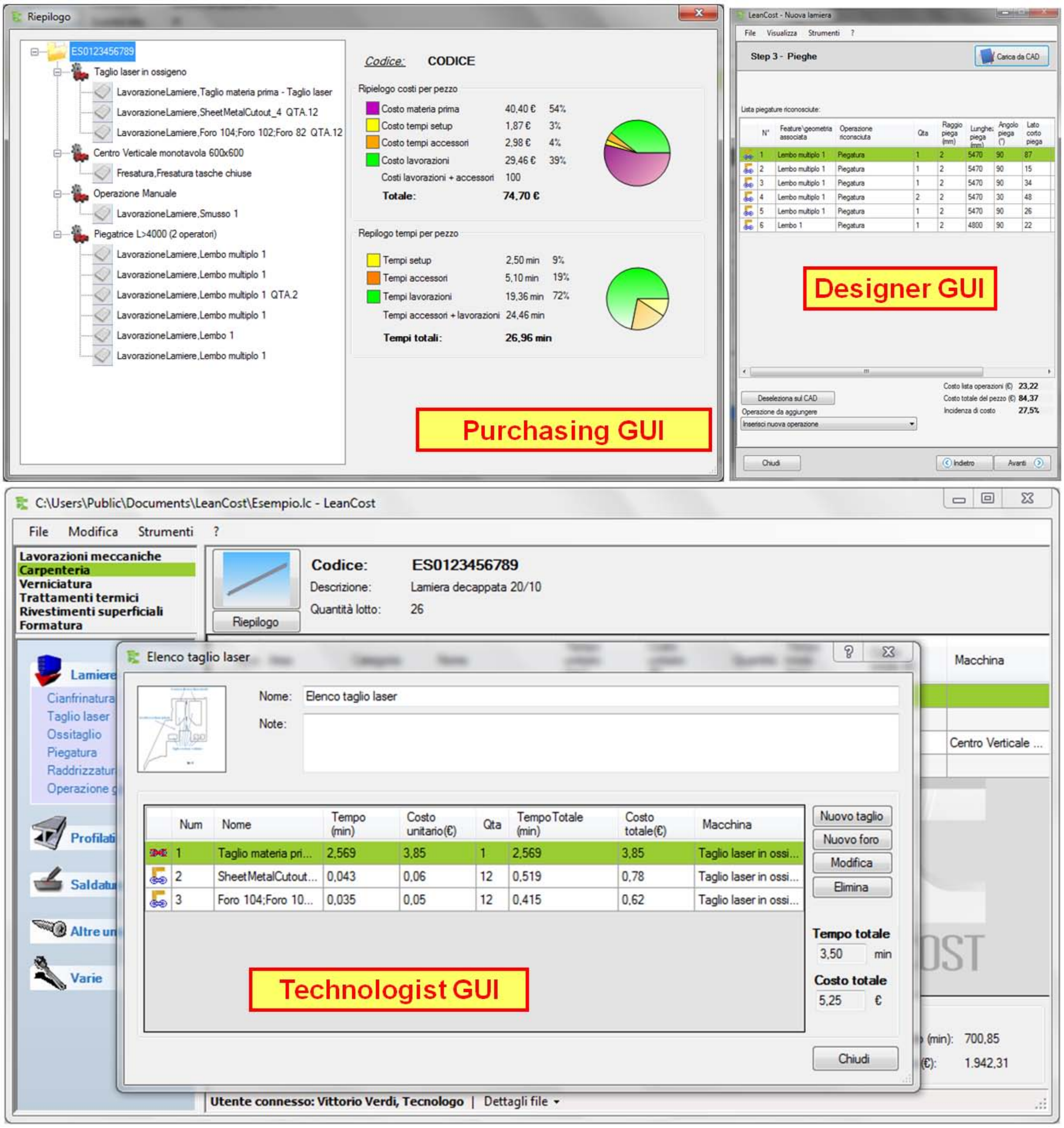


*Figure 5. Graphical User Interfaces (GUI) proposed to the users of "LeanCost", designer, production technologist and purchasing.*

## 5 CASE STUDY AND RESULTS

The LeanCost preliminary test has been performed in collaboration with a world leader company that produces woodworking machines (Biesse Group S.p.A.). In order to gather a wide set of results, LeanCost has been already implemented within other two companies, a gear manufacturer and structural metal working, with very different needs and operations between them. LeanCost has a modularity framework which allow an easy customization, using a set of plug-ins, specific for each company, where to customize operations with relative rules, reports.

As case, it has been chosen a new functional group to be designed. Two mechanical assemblies (carpentry) and two components have been approached. The first two are respectively composed by five sheets metal and ten beams (P0610P0081 code, figure 6) and one sheet metal and three beams (P1213P0064 code). All these components are welded among them. The two single components are obtained starting from an aluminium die cast stock, which are further machined by using a CNC milling.

In parallel two design teams have been activated. One of them has used the traditional tools (PLM system, excel spreadsheets, etc), on the other hand, the second team has used the PLM system and LeanCost. In this way it has been possible to make a comparison in terms of time and process efficiency.

The results of the test case are highlighted in the following tables (Tables 2, 3 and 4).

In table 2 the cost of the main manufacturing operations for the P1213P0064 is estimated and compared with the traditional formulas. After the time calculation, thanks to the formulas previously defined, the cost is obtained by multiplying the time for the unit cost of the machine where the operation is executed (1€/min). Cost represented within the table referrers only to the machining cost item (accessory cost will be considered only during the total cost calculation). This cost is defined directly by the company, considering parameters such as its depreciation charge, working hours in a day and cost of the operator.

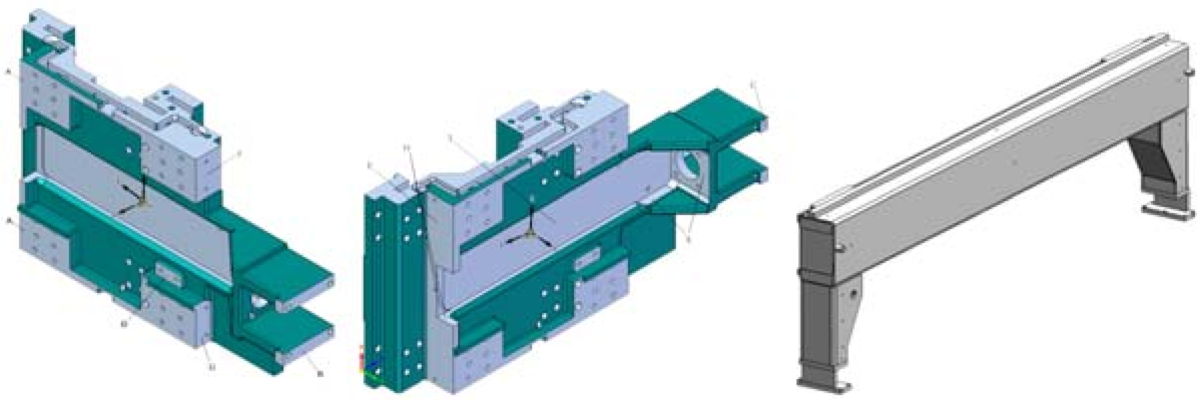

*Figure 6. The left and middle pictures show, in clear grey, the faces machined for the P0911P0064 component. The right figure shows the 0610P0081 carpentry*

*Table 2. Cost estimation of the most important operations on the P0911P0064 component.*

| Operation | Estimated Time [min] | LeanCost Estimation [€] | Estimated Cost traditional process [€] | Quantity | Machine tool |
|---|---|---|---|---|---|
| Face “A” flattering | 2,47 | 2,47 | 2,47 | 2 | Horizontal milling |
| Face “B” flattering | 0,31 | 0,31 | 0,30 | 2 | Horizontal milling |
| Open pocket milling | 7,52 | 7,52 | 7,45 | 1 | Horizontal milling |
| Closed pocket milling | 2,43 | 2,43 | 2,40 | 1 | Horizontal milling |

| | | | | | |
|---|---|---|---|---|---|
| Drilling and threading M4 hole | 0,21 | 0,21 | 0,21 | 3 | Horizontal milling |
| Boring Ø9 Hole | 0,06 | 0,06 | 0,06 | 4 | Horizontal milling |

Table 3 shows the accuracy of the estimated cost compared with the real cost calculated after functional group manufacturing.

*Table 3. Deviation analysis between Estimated Cost and real cost for the test cases.*

| Code | Lean Cost Estimation [€] | Real Cost [€] | Deviation [%] |
|---|---|---|---|
| P0610P0081 (carpentry) | 464 | 460 | -0,9 |
| P1213P0004 (carpentry) | 144 | 156 | 7,6 |
| P0911P0064 (die cast stock with milling operation) | 134 | 145 | 8,2 |
| P0914P0878 (die cast stock with milling operation) | 106 | 112 | 5,6 |

Finally, in table 4, the effectiveness of new process is highlighted in terms of time saving both during the design phase and the detailed cost estimation phase. The time saving evaluation was carried out analyzing the time spent by the designer during his work, from the conceptual design to detailed one. From the point of view of a PLM item, this time starts with the "drawn" state and finishes with the "approved" one.

*Table 4. Evaluation of the main advantages due to the implementation of the developed estimation tool within a real industrial context.*

| Code | Product design time saving [%] | Time saving (technologist) [%] |
|---|---|---|
| P0610P0081 | 20 | 70 |
| P1213P0004 | 15 | 70 |
| P0911P0064 | 12 | 50 |
| P0914P0878 | 12 | 50 |

The main results after this test can be resumed as follows. The product designer is able to rapidly evaluate if the solution can be manufactured or it must be changed by another one with similar characteristics but with smaller cost. The number of process iterations between design and product engineering phases is reduced, thanks to the significant reduction of time spent on the development of non-optimal solutions. The inexperienced designer can continuously learn the manufacturing operations with a better awareness to the final cost.

When used by the manufacturing technologist the main advantages connected to the use of the LeanCost tool are: a relevant reduction of time necessary for standard cost determination (in fact the task is limited to the verification of the cost calculated by the estimation tool during the design phase), the project modification is very easy, because all formulas and data used for the cost evaluation are stored within the tool, the tool is able to make reports in order to trace all the cost items, classified according to specific demands. Using LeanCost, a production technologist should no longer analyze each drawing to manually define the working schedule and what kind of machine use for its execution. In addition, without LeanCost, he must manually retrieve all the technological parameters required for cost calculation, such as feeding rate and cutting speed of machines, unitary cost of machines, stock and other process (heat treatments, covering, etc.) and so on. Reporting phase is now automatic and customized.

## 6 CONCLUSIONS

Agile product development requires the improvement of all processes starting from the most strategic ones. Manufacturing cost estimation is one of them. In fact product changes have an immediate impact on product cost. This paper describes an approach and a related knowledge system that can be used in order to develop a shared cost model based on analytical methodologies for cost estimation of components and welded assemblies. The developed system has been tested on different real case studies. The numerical results are really encouraging in terms of deviation in respect to the traditional processes. Also the time saving and the process efficiency are meaningfully improved.

The future work will be dedicated to the extension to other manufacturing operations and the improvement of estimation accuracy. Furthermore the system will be applied in different fields in order to investigate the robustness of approach.

## ACKNOWLEDGEMENTS

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