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# Life cycle cost for technology selection: A Case study in the manufacturing of injection moulds

R. Folgado, P. Peças *, E. Henriques

*IDMEC, Instituto Superior Técnico, TULisbon, Av. Rovisco Pais, 1049-001 Lisbon, Portugal*

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ABSTRACT

During mould design phase different approaches are envisaged to materialize part production and they must be evaluated not only in technological criteria, but also in an economical perspective. However, the comparison of such alternative approaches is not always evident for the mould designer. The solution proposed in this paper, based on the development of a life cycle cost model, fosters its application as a methodology to compare two mould manufacturing alternatives: a spray metal shell mould backfilled with a resin and aluminium powder resin and a conventional machined aluminium mould. A better mould or a better alternative is the one that incurs in fewer life cycle costs, assuming that the injected part is produced within a conformed quality.



## 1. Introduction

The European industry has been confronted with strong competitive pressures coming from the emergent productive regions of the globe (Chiang and Trappey, 2007; Li et al., 2005), where wages are substantially lower and the labour force and the all shop-floor facility work around the clock. As moulds are involved in the manufacturing chain of every industrial product, possessing a profound impact in their efficiency and robustness, and are in the critical path of any new product development, determining largely the time to market, these pressures are deeply affecting the moulds industry. The European mould-making industry, although still holding its own in sales, is rapidly losing ground in the manufacturing sector to low production cost countries (Peças and Henriques, 2004:1; Peças et al., 2009). To face competition in future, mould makers are likely to be highly technology oriented and highly innovative and unique as regards to the establishment of business models adapted for particular market niches, to which they must offer an expanded range of value added capabilities (Ribeiro et al., 2008).

The production of parts through conventional plastic injection technology can only justify its economical viability for large production volumes, due to the high cost and high manufacturing lead time of the required injection mould. For small production volumes, it is difficult or even impossible to accommodate in a competitive part cost the spreading of the mould cost. So, low cost production of large parts in small quantities implies presently the use of manufacturing solutions involving non-conventional processes like RIM or RTM, fibre reinforced resins (using open moulds) or sheet metal processes (bending, cutting and welding technologies). As a direct consequence of this fact, thermoplastic materials are frequently not considered as an option at the product design stage, constraining design issues like weight saving, complexity of the geometrical features and aesthetic issues, dimensional accuracy and surface finishing.

To cope with the progressive reduction of products life cycle and the subsequent need of a rapid market launch of new and customised products, the development of technology to allow the production of small volumes of products through injection moulding is perceived as a real breakthrough, which has become a competitive priority in mould-making industry (Williams and Exley, 2002; Bullinger, 1999). In fact low production moulds adapted for production volumes of a few hundred units demands for a huge reduction in the cost of the mould associated to a quick delivery time (Yarlagadda and Wee, 2006).

Nowadays, Rapid Tooling (RT) is emerging as a set relevant technologies used in moulds manufacturing. Since RT offers several possibilities to reduce mould manufacturing time at a reasonable cost, these technologies are traditionally used to obtain technical prototypes of the part by moulding it in a prototype mould (Rosochowski and Matuszak, 2000). However, if only a small series of final parts is required, then the definitive mould can be the prototype mould itself (Peças and Henriques 2004:2; Johnson and Kirchain, 2009). The mould manufacturing industry is embracing this option to obtain moulds for low production at a reduced cost and time (Chua et al., 2000:1, Cheah et al., 2002).

* Corresponding author. Tel.: +351 21 8417316; fax: +351 21 8419058.
*E-mail addresses:* raquel.folgado@gmail.com (R. Folgado), ppecas@ist.utl.pt (P. Peças), elsa.h@ist.utl.pt (E. Henriques).

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To understand the economic advantages of RT technologies applied to moulds for low production volumes relatively to the conventional machining based ones a comprehensive comparison study is recommended. All the relevant production steps to obtain the mould, the materials consumed, the skilled labour involved, the equipments used, the process time required, the tools and consumables spent should be considered. The identification and computation of all these data together with materials and equipments cost, and labour wages allow the estimation of the moulds manufacturing time and cost. The comparison should also include the subsequent mould-life phases like plastic part injection, mould maintenance, mould dismantling and recycling or components reuse. In fact, the selection of a mould manufacturing technology has effects not only in the manufacturing costs, but also in the mould in-use costs, in the mould duration and in its reuse/recycling potential. So, to comprehensively compare mould manufacturing options, a mould-centred Life Cycle Cost (LCC) methodology is mandatory.

The term "Life Cycle Cost" appeared somewhere in the mid 60s when it was object of interest of US government agencies (Barringer, 1998) to proceed to cost optimization when acquiring large equipment goods. Horngren et al. (1994) refers life cycle cost as the sum of all costs incurred from the "cradle" to the "grave". Barringer and Weber (1996) point to life cycle cost in a foreseen perspective. For them, life cycle costs are summations of foreseen costs from inception to disposal, for both equipment and projects as determined by analytical relations and cost factors experienced during their total life.

The objective of the LCC analysis is then to choose the most cost-effective approach from a set of alternatives considering their enlarged time scope, so the least long term cost of an ownership is achieved. The growing demand on producers to develop products/ systems that are less expensive to acquire, use, and dispose has pushed LCC as an evaluation methodology to be considered during the earliest stages of their development (Asiedu and Gu, 1998). Since it finds the solution with the lowest long term cost for a given set of requirements, a proper LCC analysis contributes to improve the competitiveness of the final product/system. For all those reasons, the LCC analysis has been used in several engineering fields by adapting the methodology to the particularities of each specific case and by setting up the desired boundaries of the problem. Research work has been published demonstrating LCC ability for design, equipment acquisition and materials selection (United States Department of Energy, 1997; Walls III and Smith, 1998; Barringer, 1997; Buncher and Rosenberger, 2005). The scope of the life cycle costing technique goes as far as analysing the labour factor considering the costs of the whole employment cycle, (Dahlén and Bolmsjö, 1996) or finding the price and warranty length of a product (Wu et al., 2006).

LCC limitations are accepted as normal restrictions as on every engineering tool. Its inherent difficulty concerns to the necessity of collecting a large amount of objective data, which most of the times is not registered or is hard to process into an LCC model (Greene and Shaw, 1990; Saccardi, 2004). An approach to deal with the difficulty of obtaining objective data in an early stage of design or development is based on stochastic modelling of cost elements, using subjective judgements (Jiang et al., 2003, 2004). More than that, as with all cost estimation techniques, these limitations can result in substantial setbacks if an organized and step-by-step procedure is not followed or if judgment is not correctly used. However, an LCC usefulness has been demonstrated by passing the test of time with practitioners who have learned how to minimize LCC limitations (Greene and Shaw, 1990; Ramasesh et al., 2010).

In this paper, the LCC analysis is applied to compare two technological solutions to produce low cost moulds for low production volumes, using objective data. A case study approach was followed, putting side by side two moulds, obtained with two distinct manufacturing technologies, but allowing the injection of the same plastic part. One of the moulds was produced based on a Rapid Tooling technology: the spray metal tooling. In the other one, a conventional manufacturing approach was used based on the machining of aluminium alloys. The LCC analysis considers not only the mould manufacturing phase, but also the injection phase, where technological characteristics of the mould, such as the thermal conductivity, affect its productivity. The comparison of the alternatives will contribute to the assessment of the economical effectiveness of the solutions based on Rapid Tooling technology in the support of mould-making businesses dedicated to the market niche of moulds for low production volumes.

It should be noted that, according to Chua et al. (2000:1), spray metal tooling is defined as an indirect soft tooling technique, in which first step involves the production of a positive master of the final part to inject. Machining or rapid prototyping technologies (i.e. Selective Laser Sintering, Laminated Object Manufacturing, …) can be used to build the initial master. Then the mould parting lines are established over the master with clay or parting boards. At this time, the surface of the two halves of the mould (core and cavity) are sprayed on generating two metallic shells. Water lines and any additional supports can be added if necessary. Afterwards, a high strength aluminium filled epoxy resin is poured into each shell to back fill the core and the cavity. The epoxy resin is similar to the material used for the epoxy moulds (Chua et al., 2000:2). The aluminium addition to the resin intends to increase the thermal conductivity of the resin, although it remains considerably lower than the conductivity of the aluminium by itself (Harris et al., 2004; Chung et al., 2003). This fact results in an increasing of the injection cycle time of the spray metal mould, when compared to the conventional metallic, which affects costs during the mould in-use phase in a life cycle perspective.

## 2. Life cycle cost analysis procedure

Based on the principles proposed by Greene and Shaw (1990) for the LCC analysis, an approach that guides the procedure through the required steps (Fig. 1) was defined. The developed procedure can be easily applied to other comparisons of mould manufacturing options, when cost comparison in a life cycle perspective is intended.

The procedure begins with the characterization of the object of study. In the present case, it involves the characterization of a mould produced with Spray Metal Tooling (SMT mould) and another produced with Conventional Manufacturing (CM mould) for very low production volumes. After defining the mould life cycle, in order to establish the borders of the analysis, it is possible to develop the LCC model. The following step is the gathering and input of data into the model. The variation of the input data allows by one side the validation of the model, through the accurate judgment of the outputs, and, by the other side, a sensitivity analysis. Finally, the results of the cost analysis can be presented and discussed.

## 3. Plastic injection moulds characterization

A mould for plastics injection is a tool used to create repeatable products with diverse geometries. In its most simple form, the mould is composed by two half dies: the cavity and the core. When these are together, they compose the geometry of the part that is intended to produce. The two moulds produced for this research inject the same plastic part (Fig. 2). They differ