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An Empirical Laser Sintering Time Estimator for Duraform PA

MASSIMILIANO RUFFO†*, CHRISTOPHER TUCK† and RICHARD HAGUE†

Abstract

This paper presents work on the development of a build time estimator for Rapid Manufacturing (RM). A time estimator is required in order to develop a comprehensive costing tool for RM. An empirical method has been used to estimate build times utilising both simulated and actual builds for a Laser Sintering (LS) machine. The estimator presented here is based upon object geometry and therefore the fundamental data driving the model is obtainable from current three dimensional Computer Aided Design (3D-CAD) models. The aim of the paper is to define a model describing the build times for a laser sintering machine either for single or multiple objects.

Keywords: Rapid Manufacturing; Time estimation; Laser Sintering; Rapid Prototyping; Cost estimation

1. Introduction

The term Rapid Prototyping (RP) is used for all techniques that allow the realisation of models by the addition of material layer by layer, starting from a 3D-CAD model. Differently from traditional machining, which work by subtracting material from a block of material, RP systems manufacture layers from liquid, powder, filaments, rolled and spooled materials (Wohlers T. 2004). Layer after layer, these machines reconstruct the object represented by a 3D-CAD model once an additional software has sliced the 3D-CAD model. When such production technology is used to produce end-use parts, it is also known as Rapid Manufacturing (RM) (Hopkinson and Dickens 2001). RM is able to exploit the concept of 'freedom of design', because tooling is no longer required. Many of the issues experienced with traditional manufacturing technology, such as split lines, draft angles, undercuts and thin wall sections in injection moulding, are removed. This allows designers to develop more imaginative and creative work (Hague *et al.* 2003).

The evolution of market requirements during the last ten years has introduced the need for faster product development and a reduced time to market (Kochan 2003A). This

† Rapid Manufacturing Research Group, Wolfson School of Mechanical and Manufacturing Engineering, Loughborough University, Leicestershire, LE11 3TU, UK

* Corresponding author. Email: M.Ruffo@lboro.ac.uk

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3 evolution, connected with the tendency to move towards customisation is leading the
4 diffusion of RM as a production method.

5
6 RM is currently being used by numerous companies, such as Renault Formula One
7 (Kochan 2003B), Rocketdyne (Sherman 2005) and Siemens Hearing Instruments (Plastic
8 2005) for the production of end-use parts. One of the issues for further uptake of RM is the
9 economy of the processes. RM machines are still expensive due to the technology being in
10 its infancy.

11
12 Of the current range of RM processes, Laser Sintering (LS) appears to be the most
13 appropriate for RM. In fact, the materials used in LS have better mechanical properties
14 compared with most of the other RM materials (Wohlersassociates 2005). Moreover, in the
15 LS process, support structures are not necessary because the initial state of the material is a
16 powder and this makes the build self supporting and it allows the production of multiple
17 parts in the vertical direction. This property gives to the LS process the highest usable
18 capacity for a given bed volume (Hopkinson and Dickens 2003). For the reasons exposed,
19 this study has been based on a 3D-SystemsTM Vanguard LS machine (3Dsystems).

20
21 Production costs are fundamental for any enterprise and to be able to estimate them
22 as accurately as possible is a necessity. RM machine investment heavily influences the
23 final cost of products (Grimm T. 2004), which adds an indirect cost not omissible in a
24 costing model. This investment must be absorbed by production and, as RM systems can
25 build different parts that require different build times, a method to assign indirect costs
26 could be based on time. Therefore, it is fundamental to have appropriate time estimation in
27 order to calculate production costs.

28
29 When talking about Rapid Manufacturing, a common phrase used is ‘design is free’;
30 however, this is not always correct. Specifically, for processes such as jetting-based
31 systems, the “freedom of design” statement is true; conversely it is not correct for laser-
32 based systems which have to trace out the cross section profile with laser beam. In
33 consequence, for the laser manufacturing processes, build times are higher for complex
34 shapes than for simple shapes.

35
36 The aim of this paper is to show which of the main geometric parameters affect the
37 time for LS. A second objective is to find the relationship defining the build time through
38 the simplest geometric variables of the part. It is fundamental to have simple variables
39 guiding the model because they will be cost drivers if the time estimator is implemented in
40 a costing model.

41 42 43 44 45 **2. State of the art**

46
47 Most conventional RP build time predictors are based on equations derived
48 statistically as a function of the total part volume, as reported by Kamash and Flynn (1995).
49 Other estimators are based on the function of the total scan length that the laser travels.
50 Chen and Sullivan (1996) studied Stereolithography systems and defined a new function
51 for the build time estimation, including new factors such as laser power, beam diameter,
52 material properties and the user’s specification of cure depth.

53
54 Recently, a new build time estimator was studied in order to complete a virtual
55 reality system able to model and simulate a LS process. The authors of the study, Choi and
56 Samavedam (2002), firstly identified the key parameters analysing previous papers on the
57 identification of factors, such as laser power and velocity (Diane *et al.* 1997, Zhou and
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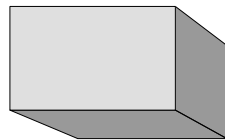
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3 Hersovici 1997, Thomson and Crawford 1995). Choi and Samavedam analysed many
4 software that were able to place parts on the bed in an efficient orientation (Thomson and
5 Crawford 1997, Woodzaik et al. 1994, Marsan et al. 1997), and finally they tried to create a
6 model able to manage all the main parameters together. In their paper, Choi and
7 Samavedam (2002) affirm that orientating a part in the minimum z-height results with
8 minimum build time. However, this is disputable in the case of multiple parts. For
9 example, when the machine bed is full of parts, their orientation does not affect the build
10 time as the total height does not vary. In general, part orientation only affects the build
11 time in a configuration in which its height modifies the total build height. Choi and
12 Samavedam's (2002) build time estimator for the LS process evaluates the time as a
13 function of laser velocity, scan distance and layer thickness, arriving at complex equations
14 that are not only difficult to understand but also to use.
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20 3. Methodology

21
22 This paper uses a different approach to time estimation in respect of previous
23 articles found in the literature. Previous estimators were based on the microanalysis of
24 timing, describing the process in detail, starting the study from the laser speed and falling
25 inevitably to complex equations. This paper presents a macro-analysis of the problem,
26 arriving at functions controlled by simple geometric parameters of the objects to be built.
27

28 In RP build time estimation there are many variables and so many different
29 conditions that it is difficult to predict them perfectly. Therefore, it is incorrect to estimate
30 a micro-variable (such as laser speed) when there are other macro-variables destroying the
31 precision of the estimation. In other words, it is inconvenient to estimate precisely the
32 smallest part of the process (i.e. a small laser head movement) when there are bigger errors
33 in other parts of the process (i.e. waiting times related to material heating).
34

35 The method used has been to "reverse engineer" the estimation problem defining
36 the inputs and the output in order to discover the model, initially seen as a black box. The
37 model could be described by a series of relationships leading to a time (output), starting
38 from some geometrical variables (inputs), as shown in Figure 1.
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42



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3 ERROR: invalidaccess  
4 OFFENDING COMMAND: --filter--
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5 STACK:
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7 /LZWDecode  
8 -filestream-  
9 [456 0 0 -180 0 180 ]  
10 true  
11 180  
12 456  
13 -savelevel-  
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