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Research Article

Analysis and Comparison of Data from Design for Manufacturing Software and Catia Software for Machining and Workpiece Manufacturing Costs

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Abstract: In this study, the output parameters of design-for-manufacturing software prepared by this group and the powerful Catia Software have been studied, in an attempt to reach a vivid notion on minimizing the costs in units manufacturing industrial work pieces and further ascertain and compare the validity of the output from the new software with those obtained from Catia. Companies around the world are in serious competition for tools that would promote their production in terms of efficiency, speed and costs. On the other hand, designers would not be able to consider products in isolation; neither can they afford to spend too much time on an engineering idea proposed by a manufacturing engineer in order to discover suitable methods for manufacturing that product. The design and manufacturing engineers, therefore, need to work as a team in order to reach optimum solutions on designs and production methods, while effectively reducing production costs at the same time. It would be imperative to establish a powerful integrity between the experts, tools, methods and resources of the design, engineering and production stages of creating a product that would win the satisfaction of customers, designers and manufacturers.

Keywords: Catia, cost, design for manufacturing software, machining, modeling, optimization

INTRODUCTION

Due to the competitive nature of the market in industrial communities today, a product needs to be designed as quickly and manufactured as economically as possible (Nam *et al*., 1998). In order to meet these market demands, various theories have been proposed, such as design for manufacturing (Hugh, 2013), design for assembly (Hu *et al*., 2011), design for quality (G.DiGironimoa *et al*., 2006), design for life cycle (Tsai *et al*., 2001) and so on, whose primary objective would be integrating the requirements of manufacturing, assembly, quality, life cycle and so on into the design process (Kuang-Hua, 2013). This would help the experts work together in a coordinated engineering environment towards the prospective product, while eliminating the need to modify the design in later stages (Vilaa and Gauchi, 2010). A product can be designed in different ways in accordance with the functional, efficiency or other demands it is expected to meet, which would mean the establishment of several organizations with different design ideas and prospects to satisfy similar practical needs.

Providing a practical solution depends on the manner the problem is described for the designer, as well as his/her professional knowledge and creativity, as there are several valid solutions to any given problem. The question would be how to discover the design with the highest value for solving the problem at hand. It is also quite possible that other, even better designs exist beyond the designer's knowledge or information. "Design for manufacturing is a tool that guides the designer towards choosing the best available design" (Corrado, 2001) and then creates the optimum design, as well as an instrument for developing and expanding ideas and beliefs. It could also be clarified that design for manufacturing combines the various data related to designing a part in order to exploit all the capabilities and advantages of the production method (Adithan, 1995). To reach the optimum design, the production engineer needs to adequately master the benefits and limitations of various production methods. Therefore, studying economic activities tends to create huge obstacles for decision-making in regard with production. The costs pertaining to energy, materials, purchased parts, workers and vital equipment and machineries should be controlled in a manner that they do not exceed their acceptable limits and thus jeopardize the profit-making prospect of the enterprise. A critical parameter in minimizing costs would thus be making the right choices and developing a clear understanding of the production costs and time estimates (Geoffrey, 1989). In this study, the parameters were held in order to evaluate the data resulting from a Design for Manufacturing and Catia Software and reach a better judgment between the two system. The final objective was an attempt to develop a

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relatively more economical software (namely, DFM) and lower the software acquisition costs previously fixed by the expensive Catia Software for interested industrial entities.

MATHEMATICAL MODEL

Estimating required parameters for determining optimum conditions: The costs pertaining to the machine and machinist (*M*) include the machinist's wage and machine's life, as well as the overhead costs of employing the machinist and using the machine. These costs are calculated differently in different workshops, but the most common method would be using Eq. (1):

$$M = W_0 + \left(\frac{\text{machinist's overhead cost percentage}}{100}\right) W_0 + M_t + \left(\frac{\text{machine's overhead cost percentage}}{100}\right) M_t \quad (1)$$

where,
w_0 = The machinist's wage
M_t = The machine's life

The overhead cost of the machinist could vary between 100 to 300% and covers items such as benefits, accommodation costs and those dedicated to establishing the official facilities for turning operations. The overhead cost of the machine includes the cost of power consumption, maintenance and probably acquiring the workshop.

In calculating the machine's life, a period is considered for the life span of the machine, during which the initial price of the machine expires. This period and the tax schemeen forced by the government vary between 2 to 10 years. In general, the following equation could be used to estimate the machine's life:

$$M_t = \frac{\text{machine's initial price}}{\text{machine's age (years)} \times \text{working hours per year}} \quad (2)$$

The proper method for estimating the costs of lathe tools depends on the tool used in each case. For lathe tools capable of being ground, the following equation could be used the grinding costs:

$$C_t = \text{grinding cost} + \frac{\text{tool's price}}{\text{number of times the tool could be ground}} \quad (3)$$

It must be noted that in practice, the number of times a lathe tool could be ground is much less than the nominal number, since few tools are blunted evenly and some parts of it may chip off or break in the process. Experience shows that the nominal number also needs to be reduced to some extent.

For tools with throw-away inserts, the cost for acquiring a sharp tool could be calculated through the following equation:

$$C_t = \frac{\text{throw-away insert's price}}{\text{average number of cutting edges on each insert}} + \frac{\text{tool post's price}}{\text{total cutting edges used during the tool post's life span}} \quad (4)$$

It must be mentioned that the average number of cutting edges to be used tends to be lower than the available cutting edges and actual number needs to be estimated.

The time needed for changing a lathe tool includes the time necessary for detaching the tool from the machine, installing the new tool, adjusting its place to commence turning and returning the machine into the process. For throw-away inserts, the following equation could be used to calculate the T_{ct}:

$$T_{CT} = \left(\frac{\text{time needed for access to next edge}}{\text{average number of cutting edges on each insert}} \times \text{average number of cutting edges on each insert} - 1\,\text{average number of cutting edges on each insert} + \text{time needed for changing}\,\text{average number of cutting edges on each insert} \quad (5)$$

The cutting speed (v_r) and life span of the related lathe tool (t_r) depend on the material and shape of the tool, the work piece material and the lathing conditions. The values of v_r can be calculated using values of *C* (cutting speed for one minute of the tool's life) for different materials and conditions of cutting mentioned in relevant reference books. For this purpose, the hypotheses of the problem for modeling are provided below.

Hypotheses of the problem for modeling:

CNC lathe's price: 300,000,000 Riyal
Operator's wage: 270,000 Riyal per day
CNC lathe's life: 10 years
Time needed for changing and re-adjustment of cutting tool: 300 sec
Cutting tool type: brazed-tip
Unproductive time for manufacturing a workpiece by the machine: 3, 600 sec
Unproductive time for manufacturing a batch of workpieces by the machine: 3, 600 + 60 sec for each workpiece
(The machine is supposed to work for 8 h a day, 5 days a week and 50 weeks a year.)
Cost of a brazed-tip tool: 25, 000 Riyal
Cost of a tool post for brazed-tip tools: 200, 000 Riyal
Workpiece length: 100 mm
Workpiece thickness: 40 mm
Roughing length: 80 mm
Honing length: 80 mm
Grooving length: 10 mm
Screw-cutting length: 40 mm
Length of facing: 40 mm
Cutting thickness: 40 mm
Feed per each round: 0.2 mm per round
Cutting speed: 120 m per minute

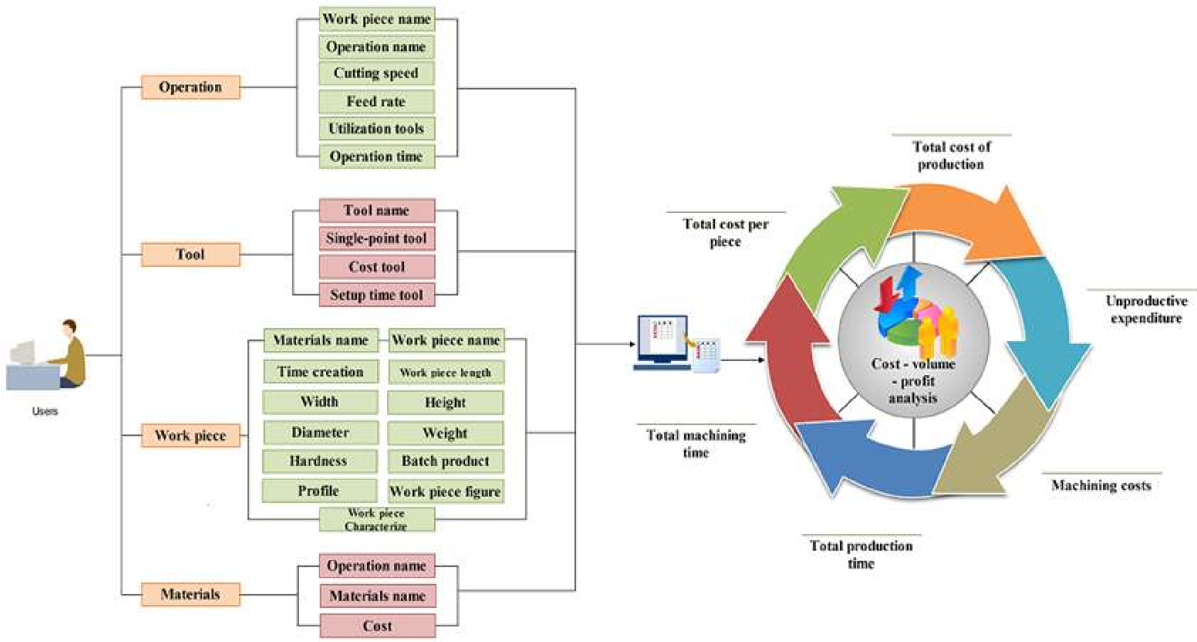

Fig. 1: Conceptual schema of the database sources in the software and their interactions

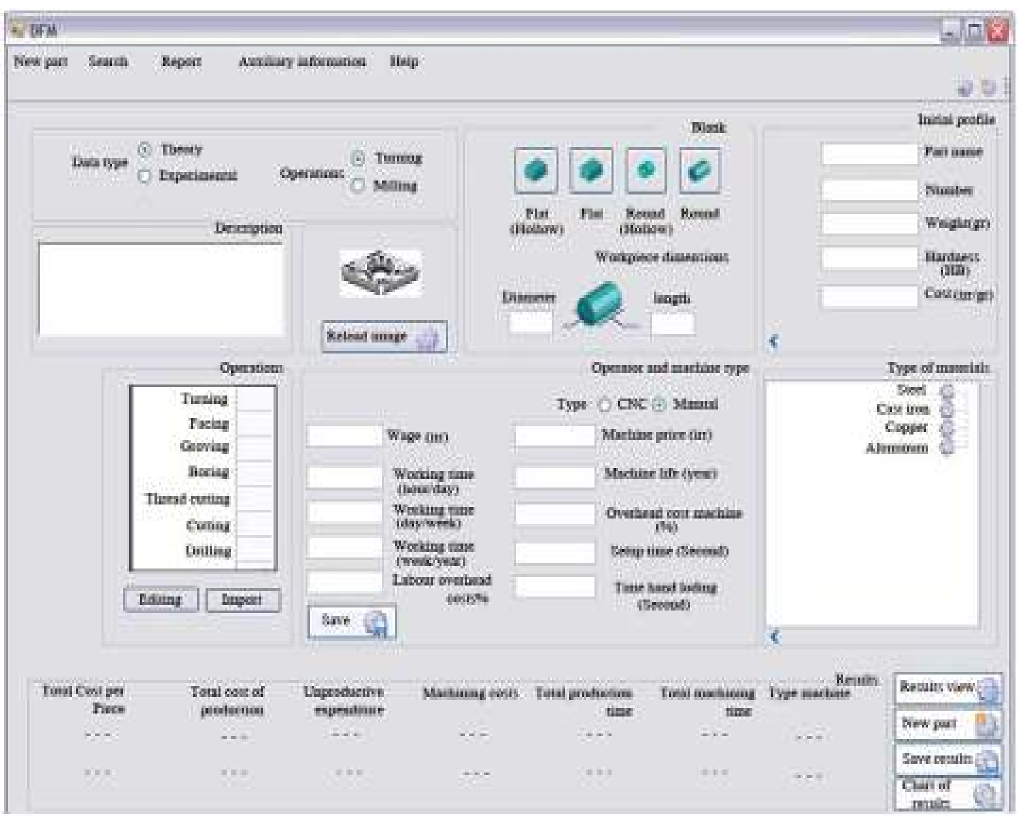

Fig. 2: A scheme of design-for-manufacturing software

Spindle rotation: 1,000 rounds per minute
Workpiece material: cast aluminum

Overhead costs of machinist and machine: 100 % (Fig. 1)

DESIGN FOR MANUFACTURING SOFTWARE

In order to exploit available computer technologies for industrial manufacturing processes, a special software was designed and implemented in regard with design for manufacturing, using". net" programming capabilities and the Microsoft SQL Server database. This software would be compatible with the majority of computer systems in the country, since it can be easily installed on all versions of Microsoft Windows. In this software environment (Fig. 2), the operator commences with entering the basic details of the workpiece and its material and would proceed to define the parameters related to unproductive expenditures, such as overhead costs, maintenance and so on. The next step would be entering the parameters related to type and material of the lathe tool and the machining parameters according to the operation type. The system would then calculate the machining time; total production time, machining costs and production costs based on the number of workpieces and would finally use the resulting data to compare the CNC machine and a manual lathe.

Figure 1 portrays a conceptual schema of the database sources in the software and their interactions. The software database employs data from various sources such as Standard Tables from American Engineers Association (George, 1997) and empirical handbooks (James, 1998), in order to make better decisions on the relevant parameters.

MODELING AND ANALYSIS OF DATE PROVIDED BY CATIA SOFTWARE AND THE NEW SOFTWARE DFM

Modeling by Catia: This section covers the modeling of the workpiece by the Catia Software, using the hypotheses mentioned above. The first step would be modeling the workpiece by the software (Fig. 3). The model would then be transferred to the machining section of the software (Fig. 4), where the machining operation would be defined with different parameters, including a spindle speed of 1,000 rounds per minute, cutting speed of 120 m per minute and the feed of 0.2 mm per round. Using the above data, the software would calculate the machining time and the total production time. The data provided by Catia Software includes six separate machining operations, namely turning, screw cutting, grooving, facing, finishing and cutting.

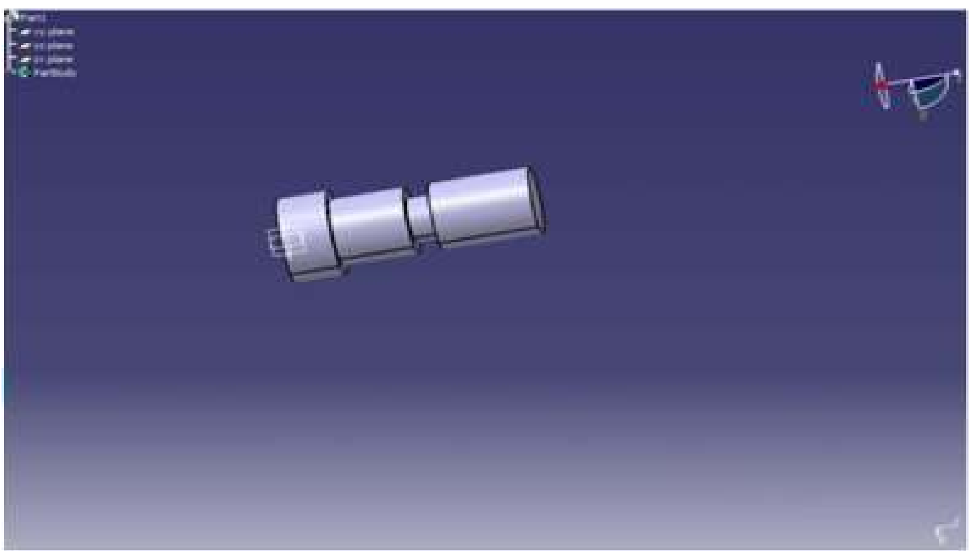

Fig. 3: Workpiece modeling by Catia Software

Table 1: Workpiece machining times calculated by Catia Model

Operation/Bache	Rough machining (sec)	Finishing (sec)	Grooving (sec)	Screw cutting (sec)	Cutting (sec)	Facing (sec)	Total time machining (sec)
1	78	31	36	31	6	6	188
100	7800	3000	3600	3100	600	600	18800
500	39000	15000	18000	15500	3000	3000	93500
1000	78000	30000	36000	31000	6000	6000	188000
10000	780000	300000	360000	310000	60000	60000	1880000

Table 2: Workpiece production times in Catia Model

Operation/Bache	Rough machining and Finishing (sec)	Grooving (sec)	Screw cutting (sec)	Cutting (sec)	Facing (sec)	Total time machining (sec)
1	3714	37	32	6	6	3795
100	21043	3733	3248	604	604	29232
500	90814	18666	16243	3022	3022	131767
1000	178027	37332	32486	6045	6045	259935
10000	1780270	373320	324868	60456	60456	2599370

Table 3: Workpiece production costs in Catia Model

Operation/Bache	Rough machining and Finishing (sec)	Grooving (sec)	Screw cutting (sec)	Cutting (sec)	Facing (sec)	Total time machining (sec)
1	101432	1326	1146	198	198	104300
100	653556	132663	114639	19865	19865	940588
500	2877723	663460	573198	99326	99326	4313033
1000	5657633	1326630	1146362	198653	198653	8527931
10000	55702207	13266305	11463623	1986536	1986536	84405207

Table 4: Machining times in DFM Model

Operation/Bache	Rough machining (sec)	Finishing (sec)	Grooving (sec)	Screw cutting (sec)	Cutting (sec)	Facing (sec)	Total time machining (sec)
1	72	30	42	29	6	6	185
100	7200	3000	4200	2900	600	600	18500
500	36000	15000	21000	14500	3000	3000	92500
1000	72000	3000	42000	29000	6000	6000	185000
10000	720000	30000	420000	290000	60000	60000	1850000

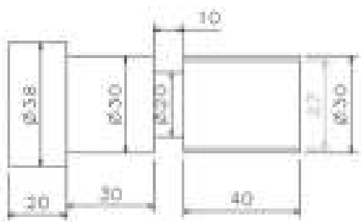

Fig. 4: Workpiece manufacturing plan

Table 1 shows the calculated data and machining times (in seconds) by Catia Software.

The model would then be transferred to the machining section of the software, where the machining operation would be defined with different parameters, including a spindle speed of 1,000 rounds per minute, cutting speed of 120 m per minute and the feed of 0.2 mm per round. Using the above data, the software would calculate the machining time and the total production time. The data provided by Catia Software includes six separate machining operations, namely turning, screw cutting, grooving, facing, finishing and cutting. Table 1 shows the calculated data and machining times (in seconds) by Catia Software. Using the data from Table 1, the Fig. 5 has been developed for the machining times: The Fig. 5 helps obtain the following equation for calculating machining times for various values:

$$Y = a+bx+cx^{1.5}+dx^{2.5} \tag{6}$$

$a = 98.87$ $b = 184.37$
$c = 0.1191$ $d = 8.29\text{e} - 6$

Calculating the machining times and considering the unproductive times would then provide the workpiece production time, the resulting data for which is demonstrated in Table 2. Using the data from Table 2, the Fig. 6 has been developed for the production times:

The Fig. 6 helps obtain the following equation for calculating and applying production times for different values:

$$Y = a+bx+cx^3+d/x \tag{7}$$

$a = 3606.66$ $b = 256.29$
$c = 3.27e - 8d = -67.99$

The times calculated out of the total production time would then be employed to reach the workpiece production cost, without considering the costs for the raw workpiece. The resulting data is demonstrated in Table 3. Using the data from Table 3, the Fig. 7 has been developed for the production costs:

The Fig. 7 helps obtain the following equation for calculating and applying production costs for different values:

$$Y = a+bx+cx^3+d\ln x \tag{8}$$

$a = 95865.161$ $b = 8429.34$
$c = 1.22e–8$ $d = 394.58$

Modeling in design-for-manufacturing software for CNC: In order to estimate production costs and times, there are different methods for analyzing the product using the related production and machining costs. Based on such analyses, several approaches to workpiece production would be proposed and considered that would generally include prospects on production cost reduction. At the time being, manufacturing industries need methods for quick estimation of workpiece costs and the equipment necessary for their production, so that their comparison would provide a holistic notion on the cost reduction potential of each proposed method. For this purpose, a Design-For-Manufacturing (DFM) software was designed, which would be elaborated on in this section. The times obtained from workpiece machining by the DFM Model in CNC are demonstrated in Table 4: Using the data from Table 4, Fig. 8 has been developed for the machining times:

The Fig. 8 helps obtain the following equation for calculating and applying machining times for different values:

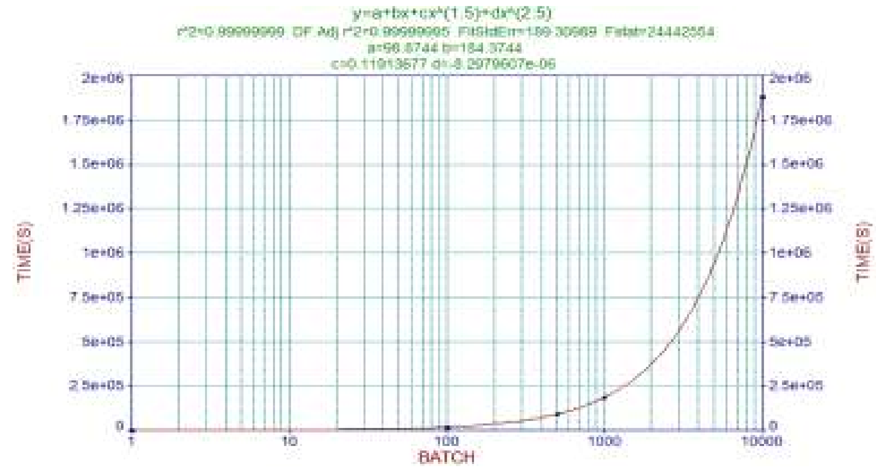

Fig. 5: Graph for machining times in Catia Model

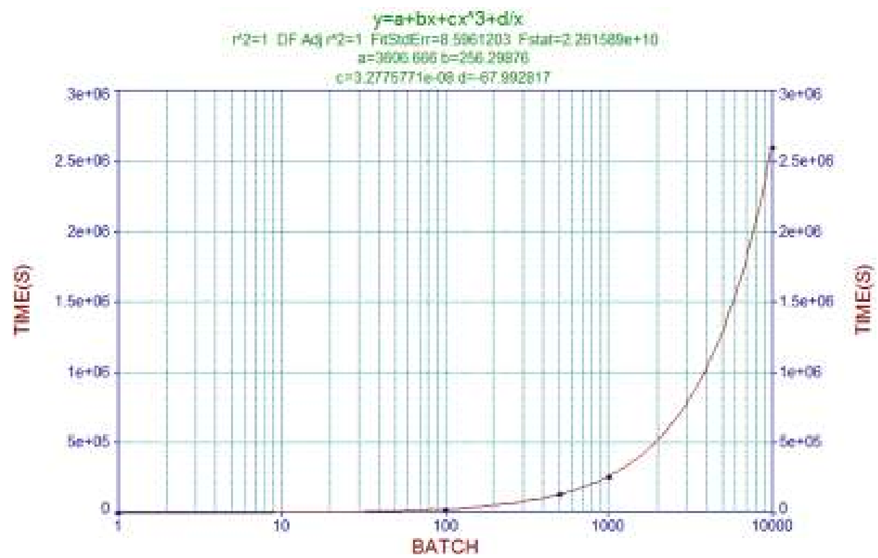

Fig. 6: Graph for workpiece production times in Catia Model

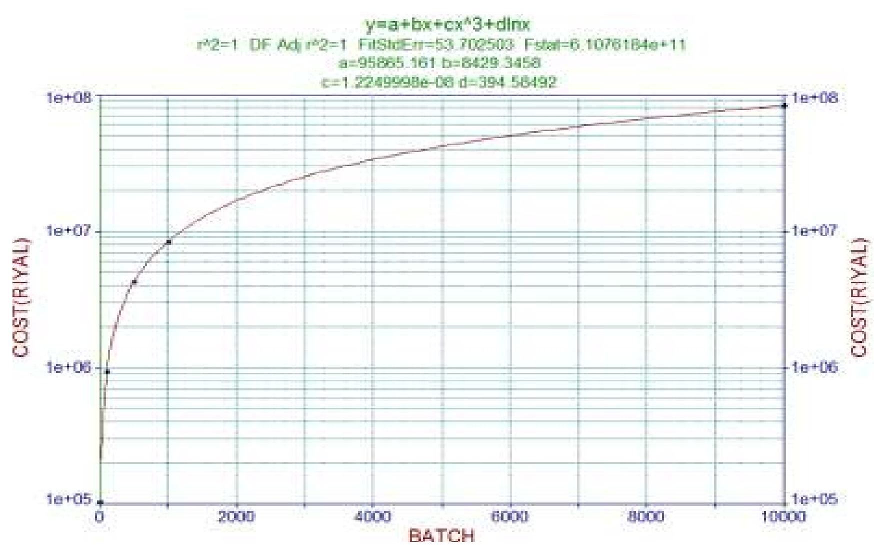

Fig. 7: Graph for workpiece production costs in Catia Model

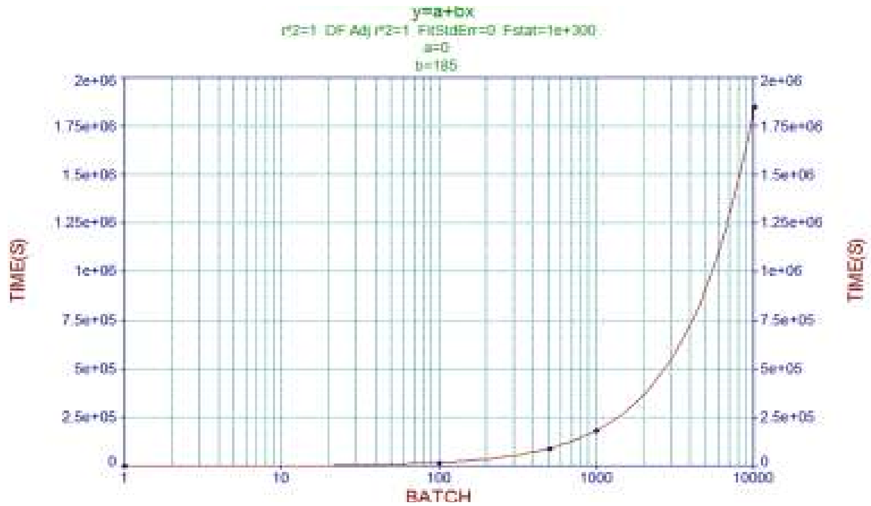

Fig. 8: Graph for machining times in DFM Model

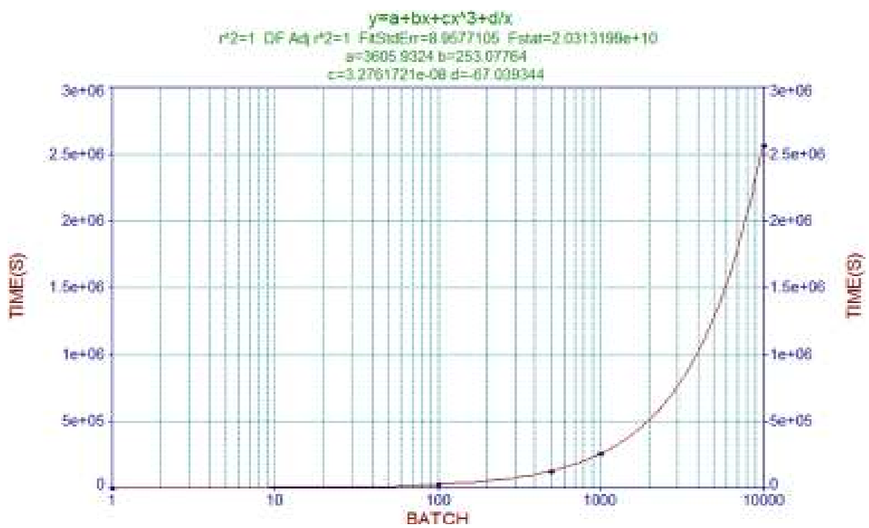

Fig. 9: Graph for workpiece production times in DFM Model

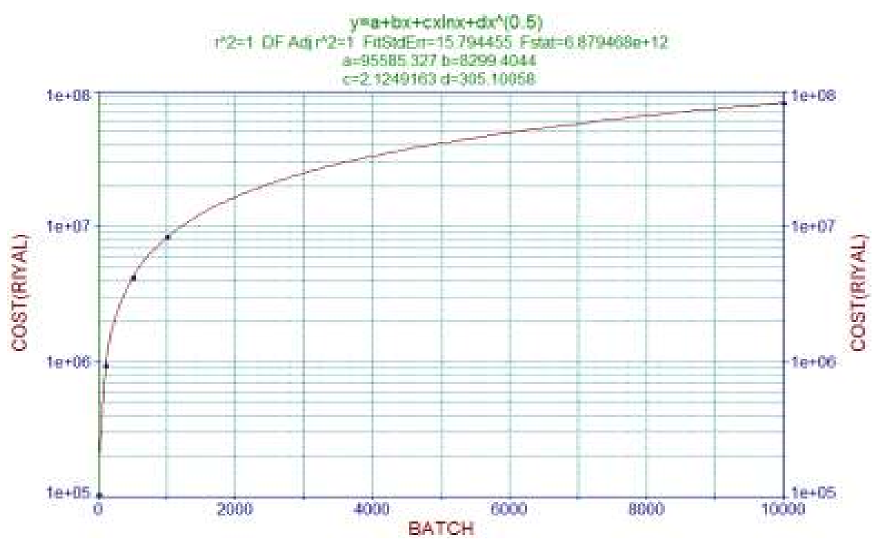

Fig. 10: Graph for workpiece production costs in DFM Model

Table 5: Workpiece production times in DFM Model

Operation/Bache	Rough machining and Finishing (sec)	Grooving (sec)	Screw cutting (sec)	Cutting (sec)	Facing (sec)	Total time machining (sec)
1	3707	43	30	6	6	3792
100	20307	4355	3039	604	604	28909
500	87140	21777	15195	3022	3022	130156
1000	170679	43555	30389	6045	6045	256713
10000	1706790	435552	303890	60456	60456	2567144

Table 6: Workpiece production costs in DFM Model

Operation/Bache	Rough machining and Finishing (Riyal)	Grooving (Riyal)	Screw cutting (Riyal)	Cutting (Riyal)	Facing (Riyal)	Total time machining (Riyal)
1	101172	1543	1074	198	198	104187
100	628076	154322	107436	19865	19865	929564
500	2751352	771610	537084	99326	99326	4258701
1000	5404999	1543220	1073797	198653	198653	8419322
10000	53172606	15432200	10737972	1986536	1986536	83315851

$$Y = a+bx \quad (9)$$

$a = 0$ $b = 185$

Calculating the machining times and considering the unproductive times would then provide the workpiece production time, the resulting data for which is demonstrated in Table 5. Using the data from Table 5, Fig. 9 has been developed for the production times:

The above graph helps obtain the following equation for calculating and applying production times for different values:

$$Y = a+bx+cx^3+d/x \quad (10)$$

$a = 3605.93$ $b = 253.07$
$c = 3.28e{-}8$ $d = 67.03$

The times calculated out of the total production time would then be employed to reach the workpiece production cost, without considering the costs for the raw workpiece. The resulting data is demonstrated in Table 6. Using the data from Table 6, the Fig. 10 has been developed for the production costs:

The above graph helps obtain the following equation for calculating and applying production costs for different values:

$$Y = a+bx+cxlnx+dx^{0.5} \quad (11)$$

$a = 95585.32$ $b = 8299.4$
$c = 2.12$ $d = 305.1$

RESULTS ANALYSIS

Comparing machining times calculated by Catia and DFM Models: First, the two models would be compared in terms of machining times of workpieces and the calculated data Table 7, would be analyzed on the related graphs.

Table 7: Machining times calculated by Catia and DFM Models

Bache	Machining times for software DFM (sec)	Machining times for software catia (sec)
1	185	188
100	18500	18800
500	92500	93500
1000	185000	188000
10000	1850000	1880000

Table 8: Workpiece production times calculated by Catia and DFM Models

Bache	Workpiece production times for software DFM (sec)	Machining times for software catia (sec)
1	3792	3795
100	28909	29232
500	130156	131767
1000	256713	259935
10000	2567144	2599370

Table 9: Workpiece production costs calculated by Catia and DFM Models

Bache	Workpiece production costs for software DFM (Riyal)	Workpiece production costs for software catia (Riyal)
1	104187	104300
100	929564	940588
500	4258701	4313033
1000	8419322	8527931
10000	83315851	84405207

The resulting Fig. 11 that the machining times calculated by the DFM Model for CNC are equivalent and similar to the data obtained from Catia Model, which confirms the validity of the data provided by the DFM Software.

Comparing production times calculated by Catia and DFM models: In this section, the production times calculated Table 8, by the two models would be compared and analyzed on the related graphs.

The resulting Fig. 12 demonstrates the fact that the production times calculated by the DFM Model for CNC are valid and could be appropriately employed for evaluating and analyzing workpiece production in manufacturing factories.

Comparing workpiece production costs calculated by Catia and DFM models: In this section, the workpiece production costs calculated Table 9, by the

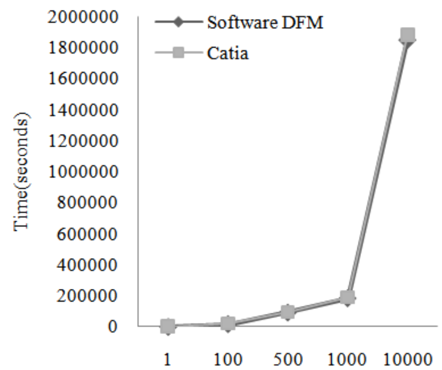

Fig. 11: Machining times of CNC models DFM and Catia

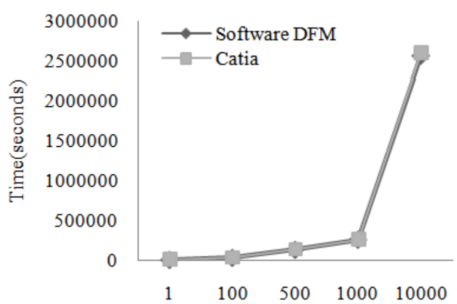

Fig. 12: Production times of CNC models DFM and Catia

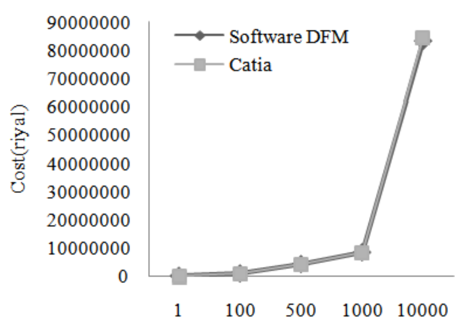

Fig. 13: Workpiece production costs of CNC models DFM and Catia

two models would be compared and analyzed on the related graphs.

The resulting graph Fig. 13 that the workpiece production costs calculated by the DFM Model for CNC are equivalent and similar to the data obtained from the powerful and expensive Catia Software, which further confirms the validity of the data provided by the DFM Software.

CONCLUSION

Design for manufacturing needs to be employed at the initial stages of the product development process, when there would be several contrasting opinions and disagreements in regard with product costs, or when it would be the most favorable opportunity for developing the product. Once the product design is complete and the workpiece has proceeded to the manufacturing stage, it would be too late to apply design for manufacturing, since any design modifications in the later stages would significantly increase the product price. As it was demonstrated by the graphs and their comparison mentioned previously, it can be concluded that the data provided by the Design for Manufacturing Software are equivalent and similar to the data obtained from Catia Software, which further validates the performance of the DFM Software. Using this software would mean a significant reduction in the costs related to acquiring efficient software systems on design for manufacturing, to be used in production complexes and industrial centers that are interested in obtaining a clear understanding of the times and costs needed for their finished products. In this way, such entities would be enabled to make the right decisions and that could be realized through applying this new dexterous software system on design for manufacturing.

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