DEVELOPING A METHODOLOGY TO PREPARE DESIGN ACCORDING TO PRODUCTION REQUIREMENT

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ABSTRACT:

This paper aims to develop a program based on a methodology to enable the preparation of design according to production requirement. Thus, the appropriate algorithms were developed to evaluate the product design according to assembly requirements and also to assess the product design according to manufacturing requirements.

The programs were applied to four case studies, two of them for Design for Assembly (DFA) and other two were for Design for Manufacturing (DFM). The study concluded that the method gives very good results for (DFA) and results of the studied two cases showed to lower the total assembly time, as well as increases the quality of the operation by lowering the probability of error expectation. However, results of (DFM) studies cases showed that the proposed program needs more development to cover all factors affecting the manufacturing processes.

The paper concluded that the suggested and developed DFA and DFM programs are a valid and beneficial approach; however, more research work is required to establish a complete and comprehensive database to match the experience of human experts in the field. Adding such database to the developed programs will increase its reliability and applicability.

KEYWORDS:
Concurrent Engineering, Design for Assembly, Design for Manufacturing.

الخلاصة :

يهدف هذا البحث إلى تطوير خوارزميات مناسبة لكي تمكن من إعداد التصاميم على ضوء متطلبات الإنتاج. لذلك طورت الخوارزميات الملائمة لكي تقيم تصميم المنتج على ضوء متطلبات التجميع وكذلك لكي تساند تصميم المنتج على ضوء متطلبات التصنيع.

طبقت البرامج على أربع حالات دراسية, اثنان منها للتصميم لغرض التجميع والاثنان الآخران للتصميم لغرض التصنيع. استنتجت الدراسة آن الطريقة أعطت نتائج جيدة جدا للتصميم لغرض التجميع ونتائج الحالتين الدراسيتين أظهرت تقليل زمن التجميع الكلي وكذلك زيادة النوعية للعملية عن طريق تقليل احتمالية الخطأ المتوقع. مع ذلك, أظهرت نتائج الحالتين الدراسيتين للتصميم لغرض التصنيع إن البرنامج المقترح يحتاج إلى تطوير اكثر لكي يغطي كل المتغيرات المؤثرة في العمليات التصنيعية.

لقد استنتج البحث على أن الطريقة المقترحة في تقييم التصميم لغرض التجميع والتصميم لغرض التصنيع باستخدام البرامج المقترحة والمطورة هو توجه فعال ومفيد, ومع ذلك يتطلب عمل بحوث اكثر لكي يرسخ قاعدة بيانات واسعة وشاملة تجاري الخبرة البشرية في هذا المجال. إضافة مثل قاعدة البيانات هذه إلى البرامج المطورة سوف يرفع من معوليتها وقابليتها على التطبيق.

INTRODUCTION:

Major changes in product design practices are occurring in all phases of the "new product development process". These changes, therefore, will have a significant impact on cost. Hence, addressing all product aspects including cost during the design stage will reduce costs [Bedworth, D. 91]. This approach is usually referred to as Concurrent Engineering (CE) [Singh, N. 96], which is a systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and assembly.

In this paper a methodology is developed as a computer program to enable the preparation of product design according to production requirements. Two phase of production tasks were selected to be the main objectives in the developed methodology. These are manufacturing and assembly

DESIGN FOR ASSEMBLY (DFA): Very often, the most significant benefits with design for assembly come by simplifying the product so that it has fewer parts which conclude on easier and faster assembly process [Bralla, J. 99].

DESIGN FOR MANUFACTURING (DFM): It is important for the manufacturing engineer to act as an advisor to the design engineer in matters of manufacturability because manufacturability matters, not only to the production departments but to the design engineer. A product design that is functionally superior and at the same time can be produced at minimum cost holds the greatest promise of success in the marketplace. Successful careers in design engineering are built on successful products. [Groover, M. 02]:

It is important to make the right manufacturing decisions early in the design process, before the cost penalty of making changes becomes too high [Esawi, A. and Ashby, M. 98]. The selection of appropriate processes for a particular part is based upon a matching of the required attributes of the part and the various process capabilities [Boothroyd, G., Dewhurst, P., Winston, K., 02].

Manufacturing process can be analyzed to determine the range of its capabilities in terms of attributes of the parts that can be produced. Included in these capabilities are shape features that can be produced, natural tolerance ranges, surface roughness capabilities, and so on. These capabilities determine whether a process can be used to produce the corresponding part attributes [Boothroyd, G., Dewhurst, P., and Winston, K., 02].

The materials selected for a design often will determine the fabrication processes that can be used to manufacture the product, its performance characteristics, and its recyclability and environmental impact. As result, engineers should acquire a robust understanding of material characteristics and criteria that one should use in making material selection.

Engineers must select the most appropriate materials for their designs, that is, materials that match both the performance requirements of the product and processing requirements for its manufacture [Voland, G., 99].

Unnecessarily tight tolerances result in high production costs, yet the tolerances should ensure that the functional performance requirements of the products stay within a satisfactory range. Tolerances which are too loose can affect the product quality, and increase the scrap rate and production costs [Ji, S., and others, 00].

In a machining operation, the machined parts may appear to be identical, but close inspection reveals dimensional differences form one part to the next. Manufacturing variations can be divided into two types: random and assignable. One important measure usually used in the evaluation of manufacturing is the process capability [Groover, M., 02] which can be defined as follows:

$$\text{Process Capability} = \mu \pm 3\,\sigma \tag{3}$$

Where μ = process mean, which is set at the nominal value of the product characteristic when bilateral tolerancing is used; and σ = standard deviation of the process.

THE PROPOSED SYSTEM ARCHITECTURE: The developed system architecture which is programmed in C^{++} language is shown in figure (1) as a block diagram. It describes the process of analyzing product designs in order to identify design changes that improve assembly and manufacturing efficiency. The process consists of the main steps: (1) DFA, (2) DFM which consist of (a) selection of materials and processes, (b) selection of tolerance and secondary operation (3) design guidelines and recommendation. References [Bralla, J. 99, Boothroyd, G., Dewhurst, P., and Winston, K., 02, Whitney, D., 04, Zendin, K., 01 and Anderson, D., 04] are used as the sources of the standard data implemented in the developed system program.

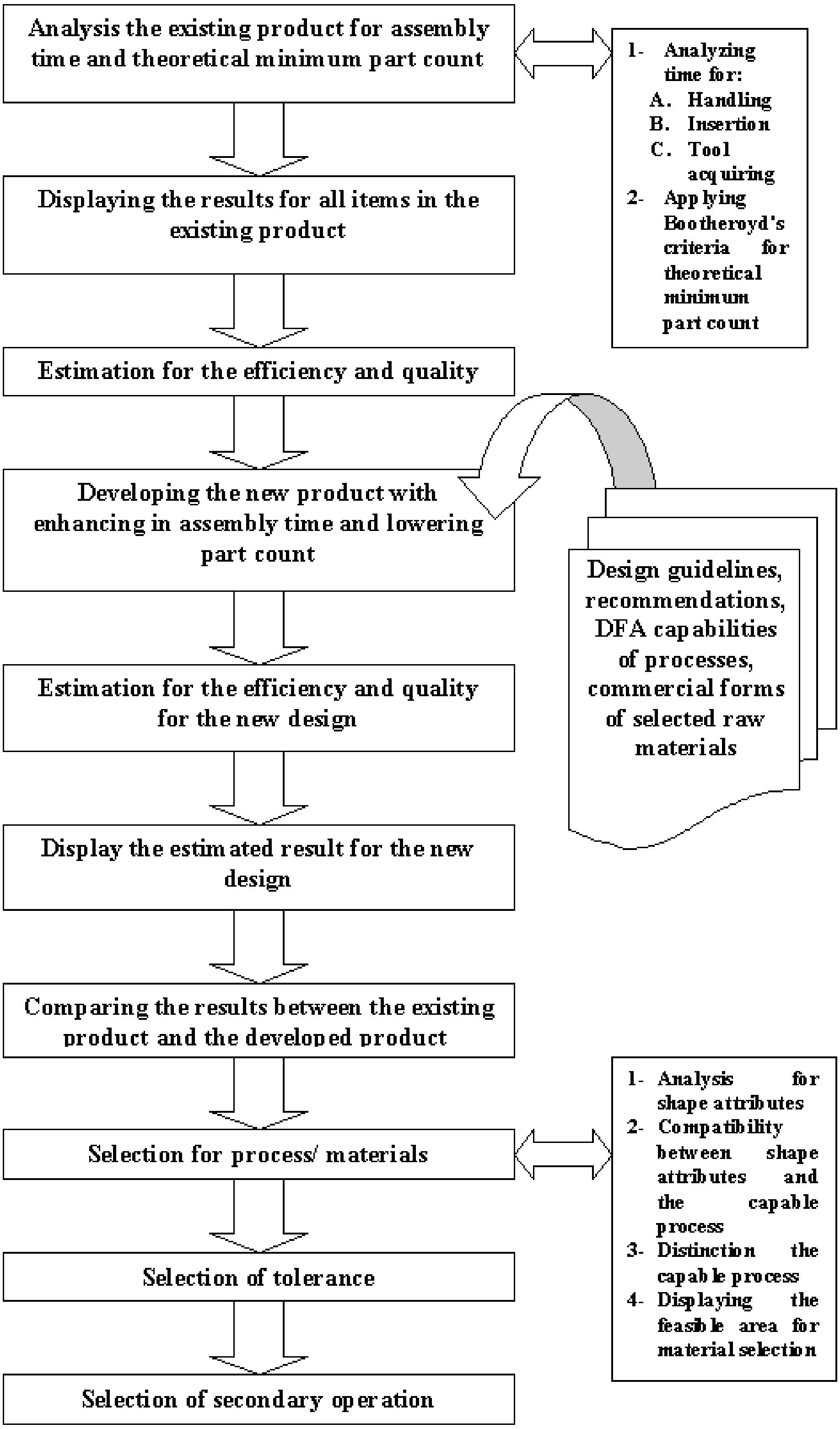


Figure (1) Block diagram of the proposed system

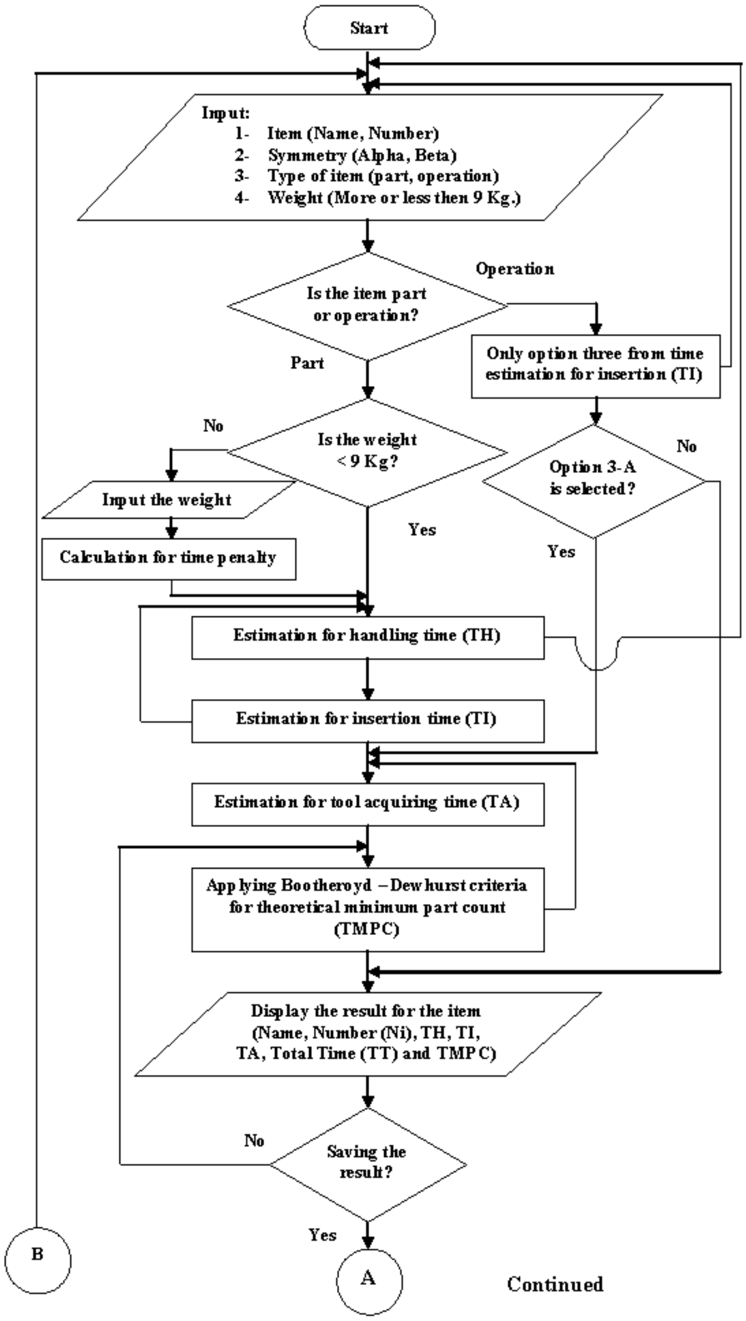
A. Design for Assembly: The part of the developed program that deals with the DFA is illustrated as a flow chart in figure (2), and starts with a main menu to acquire the followings:

a. Input:

- Product's name.
- Item's name.
- Item's number.

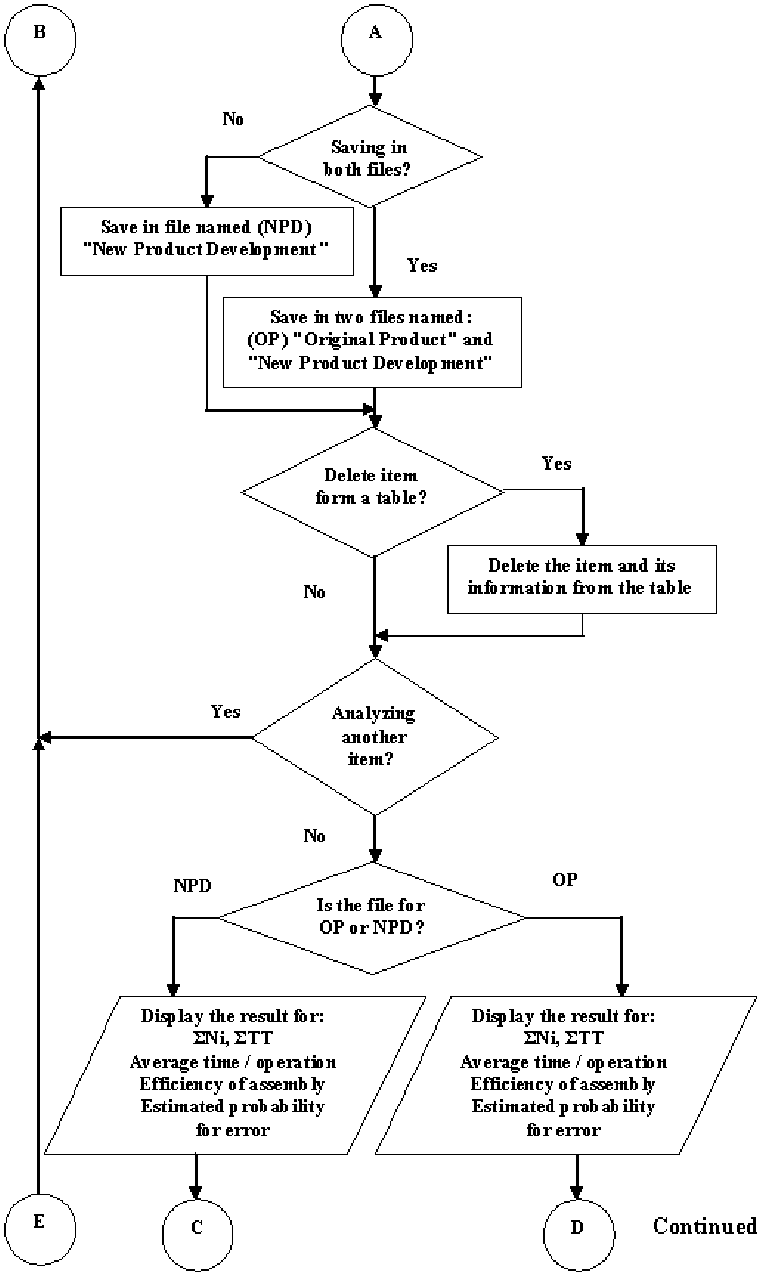
b. Select symmetry angle degree for both Alpha[1] and Beta[2].

- Type of item as part or operation.
- Part weight as less then 9 Kg. or equal or more then 9 Kg (see figure (3)).



[1] **Alpha symmetry:** it is the rotational symmetry of a part about an axis perpendicular to its axis of insertion. For parts with one axis of insertion, end-to-end orientation is necessary when alpha equals 360 degrees, otherwise equals 180 degrees.

[2] **Beta symmetry:** It is the rotational symmetry of a part about its axis of insertion. The magnitude of rotational symmetry is the smallest angle through which the part can be rotated and repeat its orientation. For cylinder inserted into a circular hole, beta equals zero.


B
A
No
Saving in both files?
Save in file named (NPD) "New Product Development"
Yes
Save in two files named: (OP) "Original Product" and "New Product Development"
Delete item form a table?
Yes
Delete the item and its information from the table
No
Yes
Analyzing another item?
No
NPD
Is the file for OP or NPD?
OP
Display the result for: ΣNi, ΣTT Average time / operation Efficiency of assembly Estimated probability for error
Display the result for: ΣNi, ΣTT Average time / operation Efficiency of assembly Estimated probability for error
E
C
D
Continued

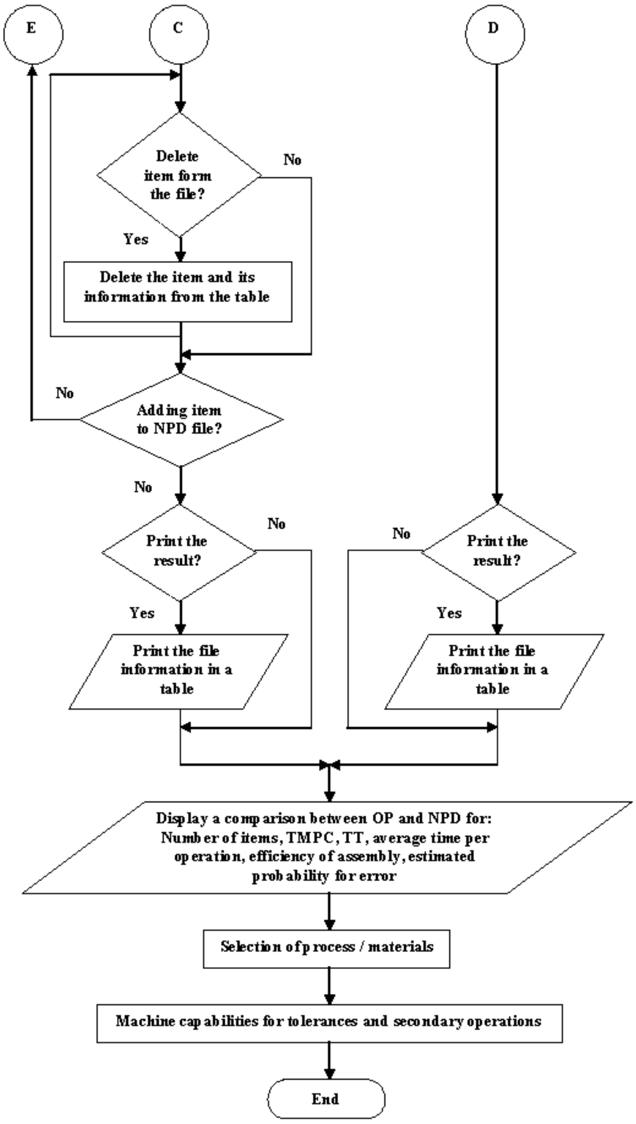


Figure (2) Main flow chart of the proposed program

(A – 1) Time Estimation for Handling: The flow chart of the handling time estimation module is shown in figure (4). However, the flow chart for options one, two, three and four from the handling time estimation module is shown in figures (4 – a), (4 – b), (4 – c) and (4 – d) respectively.

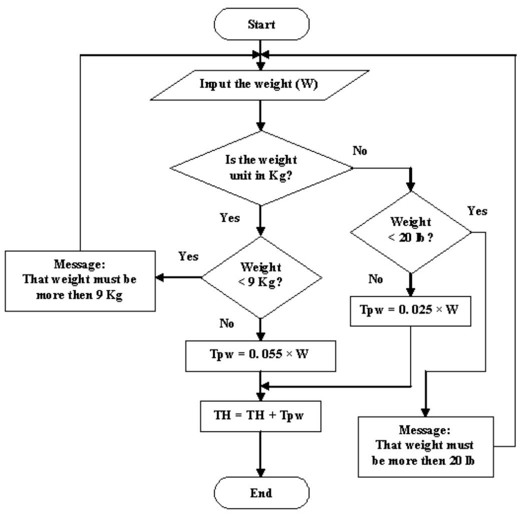


Figure (3) Flow chart of the effect of weight on handling time estimation module

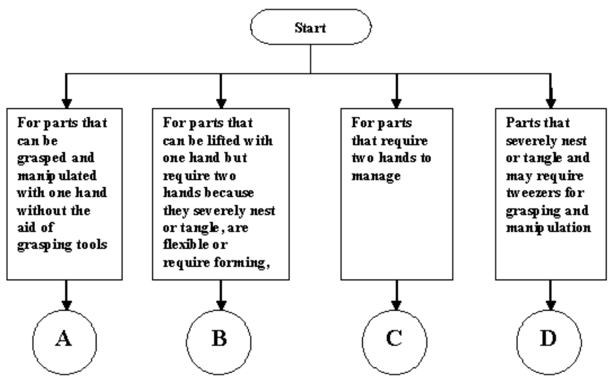


Figure (4) Flow chart of the handling time estimation module

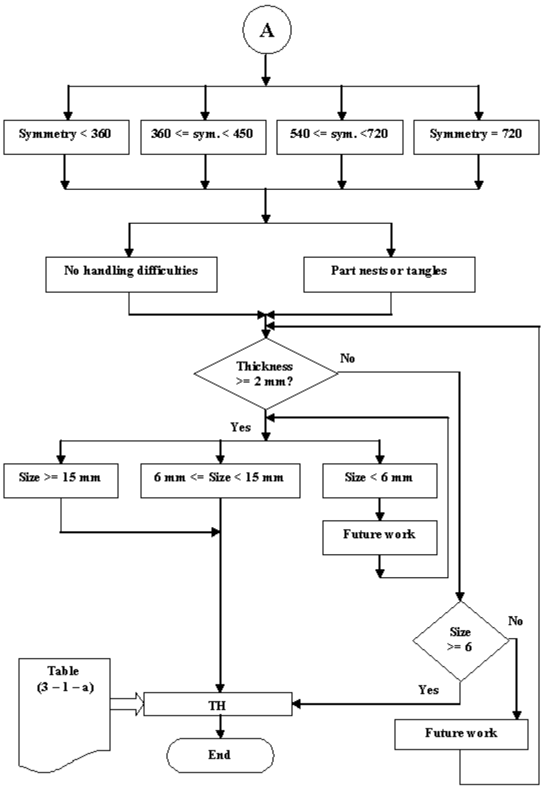


Figure (4 – a) Flow chart of the handling time estimation module for the parts that can be grasped and manipulated with one hand without the aid of grasping tools

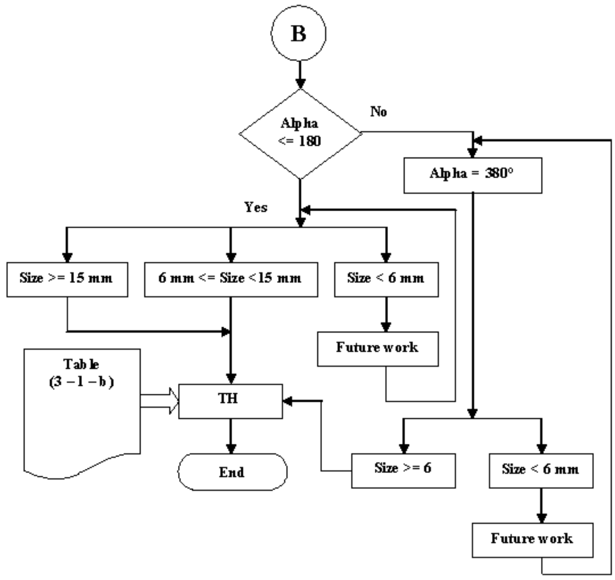


Figure (4 – b) Flow chart of the handling time estimation module for parts that can be lifted with one hand and require two hands

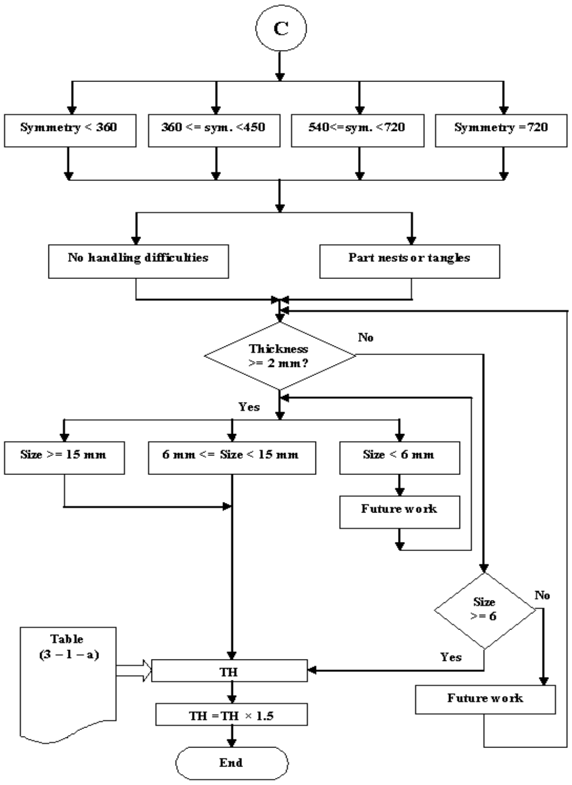


Figure (4 – c) Flow chart of the handling time estimation module for parts that require two hands for manipulation

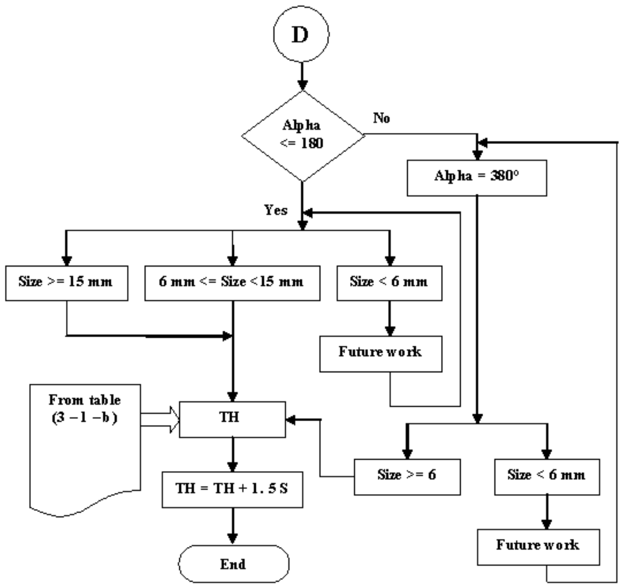


Figure (4– d) Flow chart of the handling time estimation module for parts that severely nest or tangle and may require tweezers for grasping and manipulation

(A – 2) Time Estimation for Insertion: The flow chart that carries insertion time estimation is shown in figure (5). The flow chart for options one, two and three from the insertion time estimation module is shown in figure (5 – a), (5 – b) and (5 – c) respectively

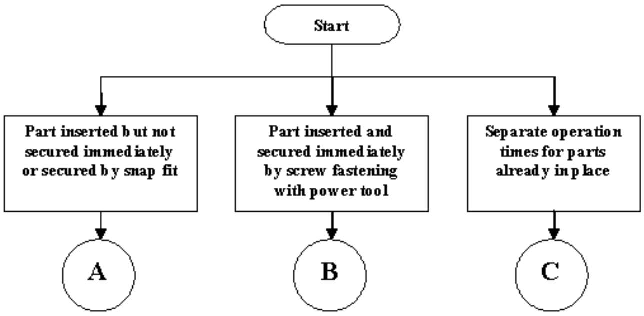


Figure (5) Flow chart of the insertion time estimation module

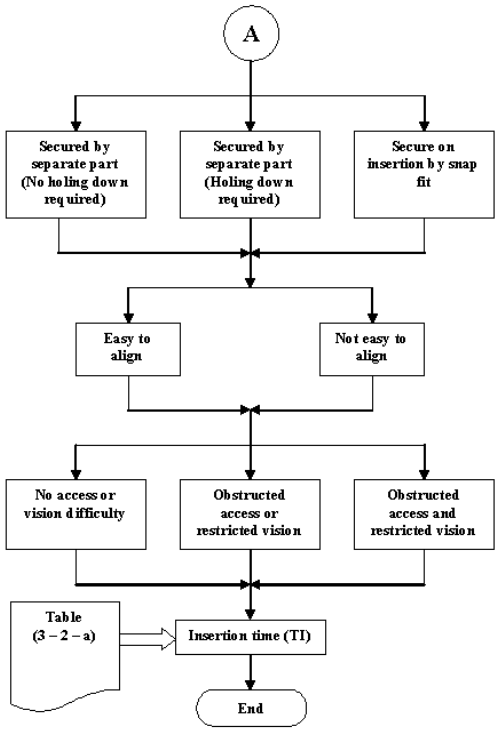


Figure (5 – a) Flow chart of the insertion time estimation module for parts inserted but not secured immediately, or secured by snap fit

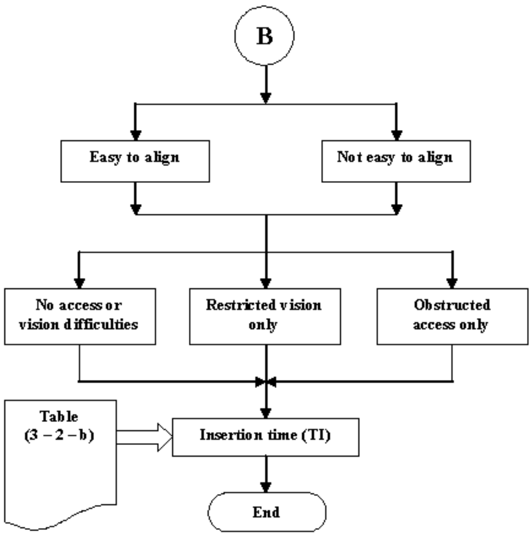


Figure (5 – b) Flow chart of the insertion time estimation module for parts inserted and secured immediately by screw fastening with power tool

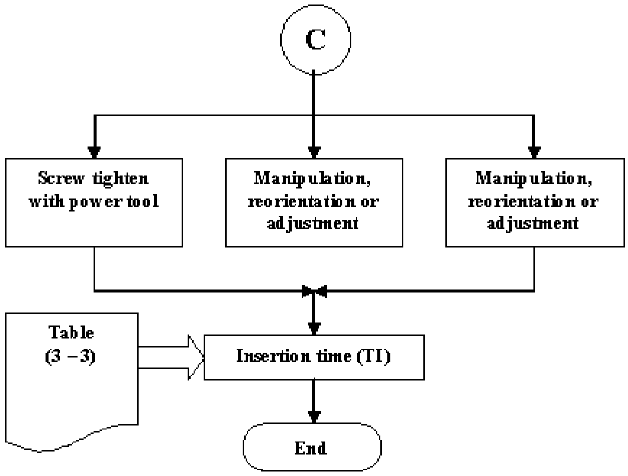


Figure (5 – c) flow chart of the insertion time estimation module for parts inserted separate operation times for solid parts already in place

(A – 3) Time Estimation for Tool Acquiring: The flow chart that represents this part is shown in figure (6).

(A – 4) Theoretical Minimum Part Count Module: The flow chart that represents this module is shown in figure (7).

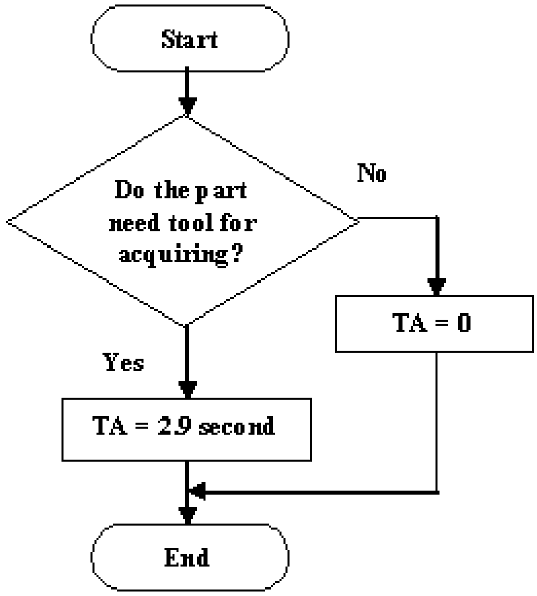


Figure (6) Flow chart for acquiring time estimation module

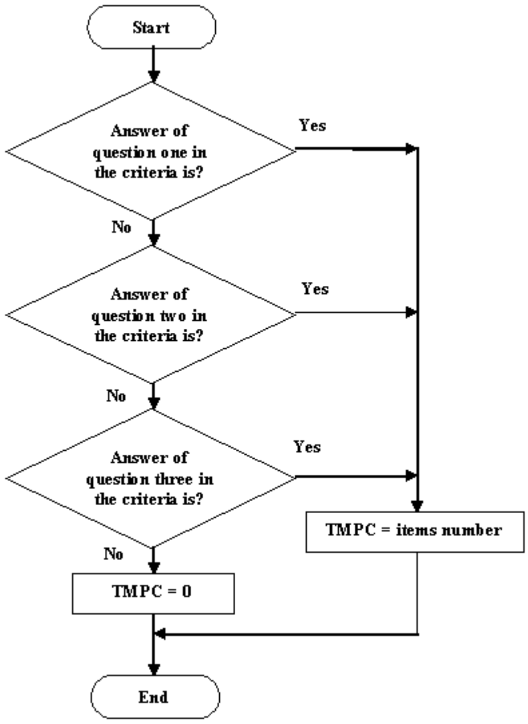


Figure (7) Flow chart of the Theoretical Minimum Part Count (TMPC) module

(A – 5) Creation of the Table "Original Product": This table contains columns for: name of the item, number of items, handling time, insertion time, acquiring time, total time and theoretical minimum part count.

In the end of these columns the user can see a row with the summation of:

a) Number of items.
b) Total time.
c) Theoretical minimum part count.

Results of these columns gives the user quick estimation about the design quality and error expectation in the production process, where the high number of items, total time, and TMPC means low quality and more error expectation in the production process. Lowering of any of these results may raise the quality. TMPC gives the user the minimum number of parts which required not to be exceeded when changing the design in the new product development and give a target for raising the quality and lowering error expectation in the production process whereas trying to be closer to that number, and away to identify possible simplifications in the product structure.

In the end of that table the user can see the results of the followings:

- Average time per operation.
- Percentage efficiency of the assembly (DFA index).
- Percentage estimated error probability.

(A – 6) Creation of the Table "New Product Development": The "New Product Development" table is designed to help in the evaluation of the new design, hence it contains the related information to the "Original Product" table through it belongs to the new design to ease comparisons.

(A – 7) The Comparison between Two Designs: The last menu in DFA analysis program makes a comparison between the two preceding files, this comparison includes:

A. Item Number.
B. Total time.
C. Results of TMPC.
D. Average time per operation.
E. Efficiency of the assembly.
F. Estimated probability.

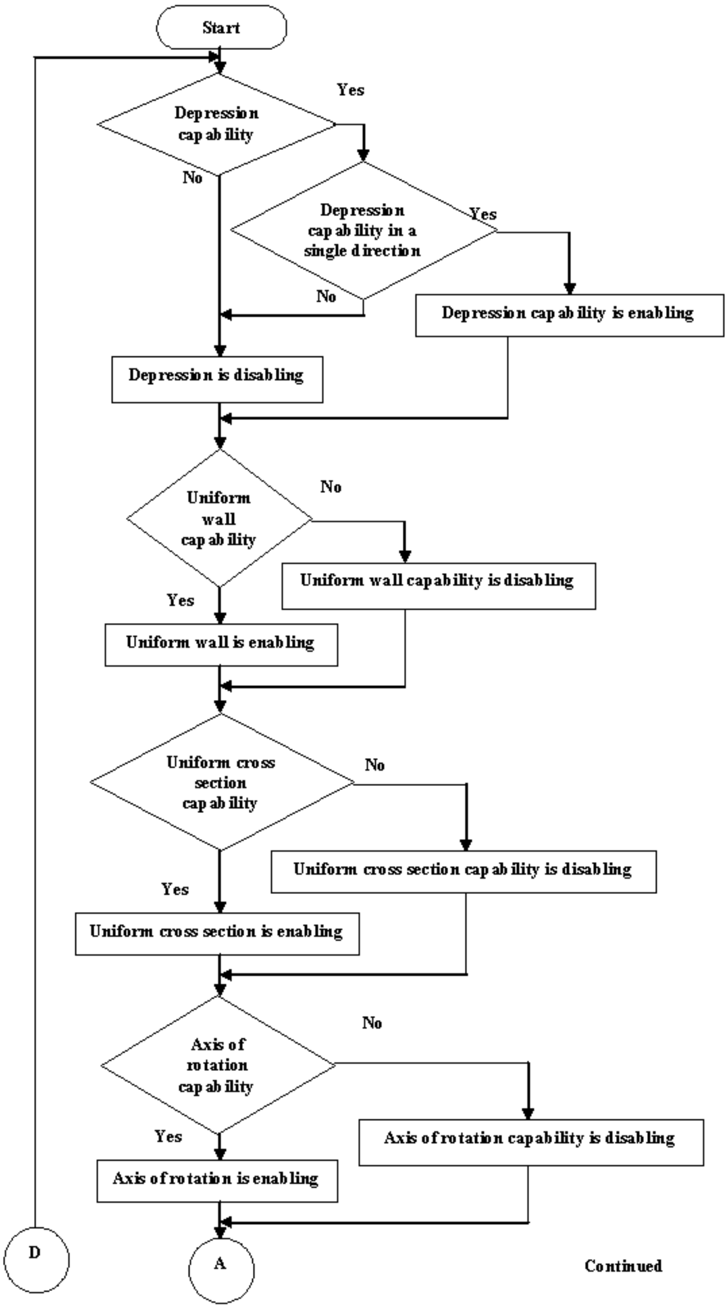
The program then gives a weight to the part count and time consuming in the assembly operation which can be converted to a cost affecting the product design.

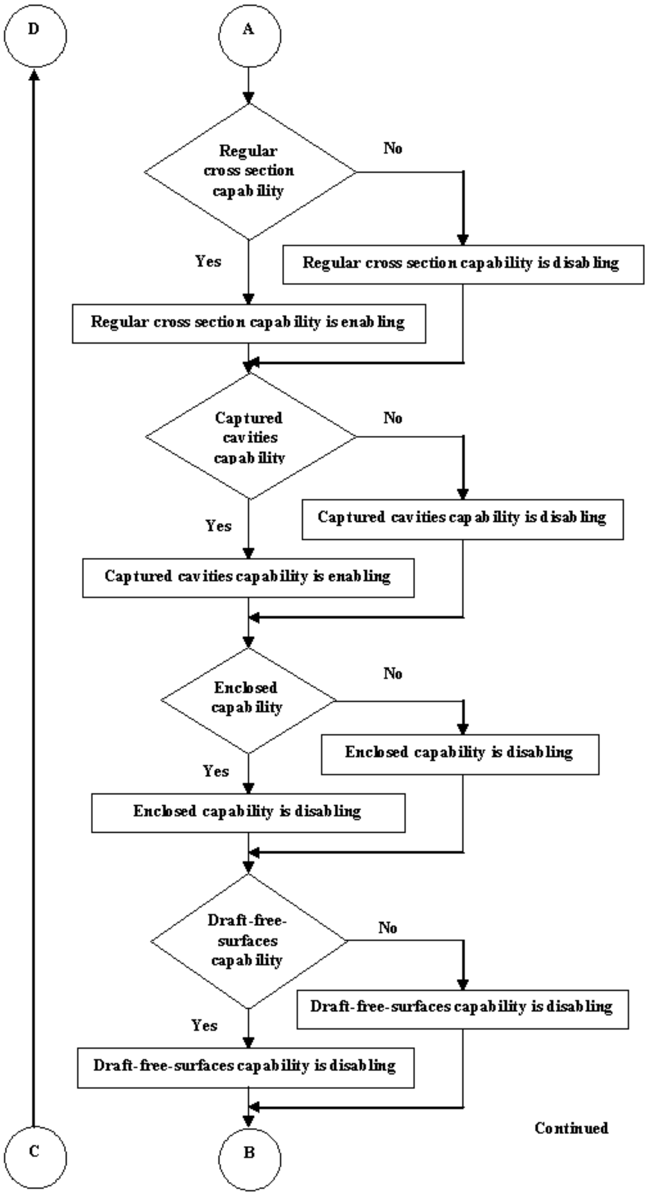
The program is aimed to work with parts that are within easy reach, are not smaller than 6 mm in size, do not stick together, and are not fragile or sharp.

B. Design for Manufacturing: The developed DFM program is aimed to:

1. Appropriate process / material selection based on realistic cost estimates.
2. Establishing or highlighting the relationships between part features and manufacturing costs for a given process.

(B – 1) Selection of Materials and Processes: This part of program is systematic procedure for selection of primary process/ material combinations. Such procedure operates by eliminating processes and materials as more detailed specification of the required part's attributes occurs. The flow chart that represents the selection of material and process is shown in figure (8).


Start
Depression capability
Yes
No
Depression capability in a single direction
Yes
No
Depression capability is enabling
Depression is disabling
Uniform wall capability
No
Yes
Uniform wall capability is disabling
Uniform wall is enabling
Uniform cross section capability
No
Yes
Uniform cross section capability is disabling
Uniform cross section is enabling
Axis of rotation capability
No
Yes
Axis of rotation capability is disabling
Axis of rotation is enabling
D
A
Continued


D
A
Regular cross section capability
No
Regular cross section capability is disabling
Yes
Regular cross section capability is enabling
Captured cavities capability
No
Captured cavities capability is disabling
Yes
Captured cavities capability is enabling
Enclosed capability
No
Enclosed capability is disabling
Yes
Enclosed capability is disabling
Draft-free-surfaces capability
No
Draft-free-surfaces capability is disabling
Yes
Draft-free-surfaces capability is disabling
Continued
C
B

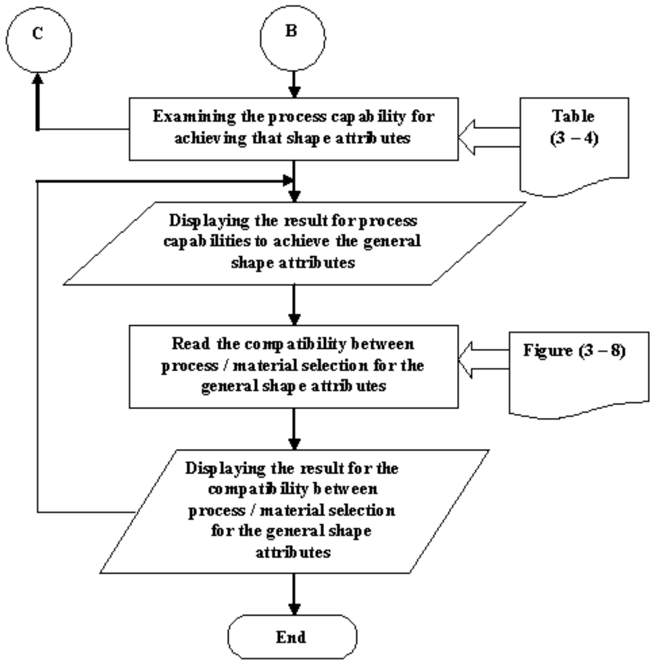


Figure (8) Flow chart of selection of materials and processes module

The program gives the compatibility of the selected shape attribute with the following manufacturing process: Sand casting, Investment casting, Die casting, Injection molding, Structural foam molding, Blow molding (extrusion), Blow molding (injection), Rotational molding, Impact extrusion, Cold heading, Closed die forging, Powder metal parts, Hot extrusion, Rotary swaging, Machining (from stock), ECM, EDM, Wire – EDM, Sheetmetal stamp /bend, Thermoforming and Metal spinning

The program displays the compatibility between all the capable manufacturing processes for doing the shape attributes with the following materials: Cast iron, Carbon steel, Alloy steel, Stainless steel, Aluminum and its alloys, Copper and its alloys, Zinc and its alloys, Magnesium and its alloys, Titanium and its alloys, Nickel and its alloys, Refractory metals, Thermoplastics and Thermosets.

All manufacturing processes that are incapable of achieving the shape attribute are displayed by the program with shaded colour for all available materials.

All manufacturing processes that are capable of achieving the shape attribute are displayed by the program with white, gray and black cells for normal practice, less common and not applicable for practice with each particular material.

The obtained combinations can then be ranked by other criteria, such as estimates of manufacturing costs.

(B – 2) Machine Capabilities for the Selected Tolerances and Secondary Operation: The developed program flow chart that represents this part is shown in figure (9).

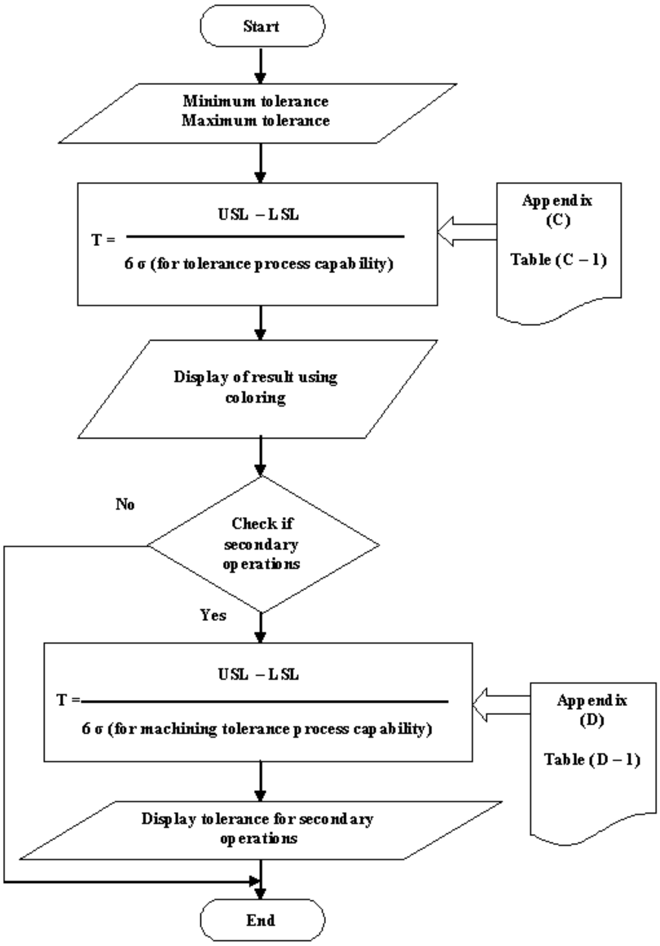


Figure (9) Flow chart of machine capabilities for tolerances and secondary operations module

The program displays the process capability index C_p for tolerance and to all manufacturing process that are examined in the previous section.

C_p index is displayed with five colors; every color refers to different area of C_p.

From the C_p area, the user can distinguish if the specified tolerance is inadequate, sufficient or tighter than necessary for a particular manufacturing process, and if it needs a secondary operation.

If the tolerance is inadequate, and needs a secondary operation, the program displays the machine capability of following machining processes operation: Rough machining, Standard machining, Fine machining, Grinding and Honing.

C. Design Principles and Guidelines

The proposed and developed system gives design principles and guidelines as a help in the program to enable the designer to develop the new design to be easer in manufacturing and assembly. These help include:

C – 1 Capabilities of the Manufacturing Processes: The proposed program displays the main capabilities of the twenty- one manufacturing processes that deals with many properties, comments and guidelines such us: Part size, Tolerances, Surface finish, Shapes produced competitively, Process limitations, Typical application, Comments, Typical characteristics of that manufacturing process, Economic production quantities and General design considerations.

C – 2 Design for Manufacturing and Assembly Guidelines: The proposed program displays about forty guidelines for manufacturing and assembly to help the designer changing the existing design to a better developed one.

C – 3 DFA Compatibility Attributes: The program also displays the main compatibility of attributes of the twenty- one manufacturing processes together with the related DFA guidelines. The attributes are: Part consolidation, Alignment features and Integral fasteners.

C – 4 The Common Commercial Forms of Selected Raw Materials: The program displays a table with thirteen cells containing thirteen materials with their commercial form availability in the market: Ingots for casting, Molding compounds, Round bars, Rectangular bars, Tubing, Sheets, Foils or films, Wires and Powder for sintering.

The displayed table also include whether these material forms are usually available, have limited availability or they are rarely or never available. Hence the designer can make the decisions with initial information about the availability of selected raw material.

IMPLEMENTATION RESULTS AND DISCUSSION

A. Design for Assembly: Two case studies are given these includes: Electrical shaver cover (figure 10) and Ball pen (figure 11).

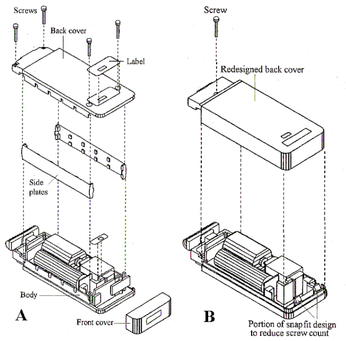


Figure (10) The electrical shaver cover. (a) The original design. (b) The suggested redesign.

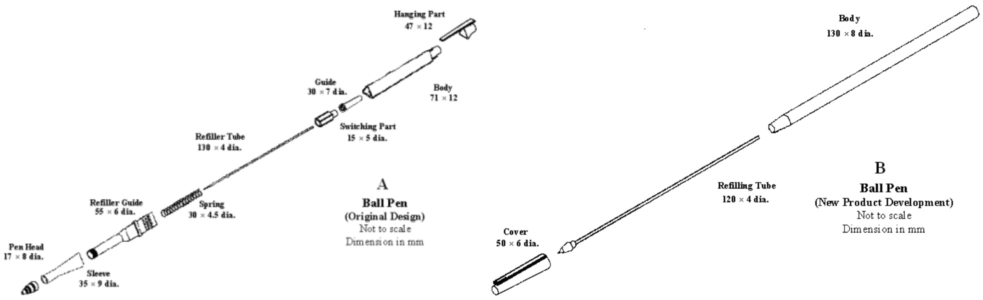


Figure (11) The ball pen. (a) **The original design**. (b) **The new developed design.**

(A – 1) Electrical Shaver Cover Case Study: The original subassembly consists of nine parts: the back cover, the front cover, two side plates that slide into place on the body and are then held in place by the back cover, four screws to secure the back cover to the body, and a label. The redesigned back cover subassembly consists of two parts, a redesigned back cover, and a screw in addition to the body.

The design data of the electrical shaver cover is analyzed step by step and input into the developed program. Results of the program are gained in the form of two tables namely "The original product table" and "The new product development table" which are shown in figures (12) and (13) respectively. However, program results shown in figure (14) presents comparison between the original and the modified design.

According to the acquired results the following enhancements to the design are gained when using the modified design:

a. The number of items decreased by 70 %
b. The total time decreased by 77 %
c. The average time per operation decreased by 23.6 %

d. The efficiency of the assembly increased by 4 times
e. The error expectation probability decreased by 84 %

It is worth to know that the modified design is made to follow the guidelines implemented in the developed program.

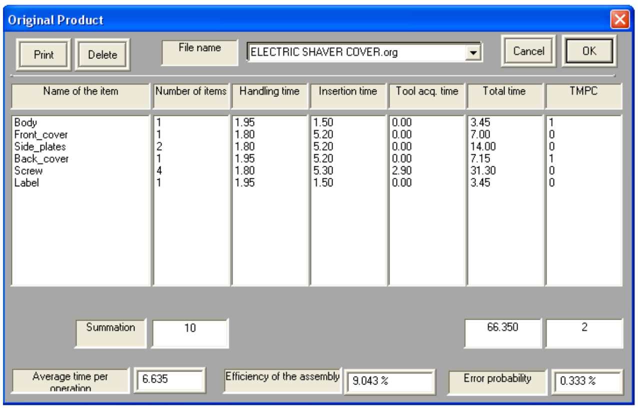


Figure (12) Results of the original design of the electric shaver cover

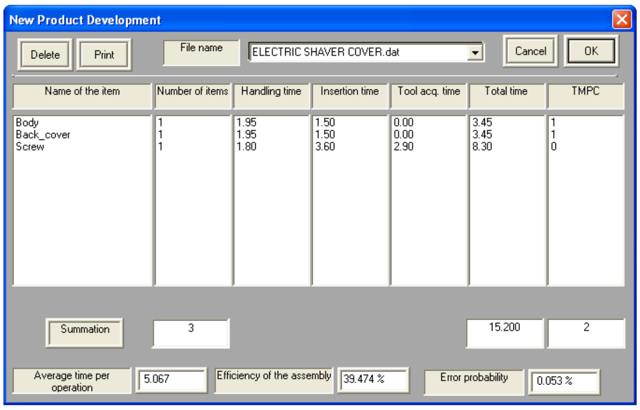


Figure (13) Results of the new product development of the electric shaver cover

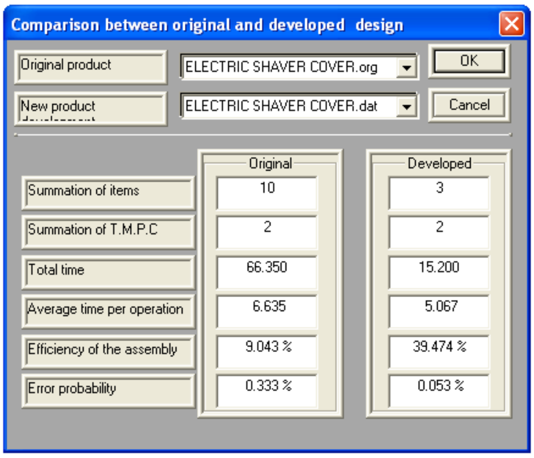


Figure (14) Comparison results of the original and the modified design for the electric shaver cover as acquired from the developed DFA program

(A – 2) The Ball Pen Case Study: A proposed pen design consists of nine parts, namely: body, hanging part, guide, switching part, refilling tube, spring, refiller guide, sleeve, and pen head. The redesigned pen consists of only three parts: Body, refilling tube and the cover.

Two ball pens that match the two designs were taken from the market by the researcher. Tests were conducted to disassemble and reassemble these two ball pens repeatingly for 30 times each to estimate the actual assembly time.

The two ball pens data were analyzed step by step and input to the DFA program which is shown in figures (15) and (16) respectively. However, figure (17) presents the acquired comparisons of results between the two cases of the pen assembly as given by the developed program. It can be seen from these results that the new design of the ball pen which follows the recommendations and guidelines stated in the developed DFA program has enhanced the assembly operation as follows:

a. The number of items decreased by 70 %
b. The total time decreased by 76.7 %
c. The average time per operation decreased by 22.45 %
d. The efficiency of the assembly increased by 4.3 times

e. The error expectation probability decreased by 91.4 %

It is obvious from these results that the enhancement of the assembly operation when implemented in the new design reduced the time required for the assembly operation by about 4.3 times as acquired by the developed DFA program. This reduction of time approximately matches the reduction of time acquired from the actual assembly operations that were conducted by the authors of this paper where about 4.2 times reduction was achieved.

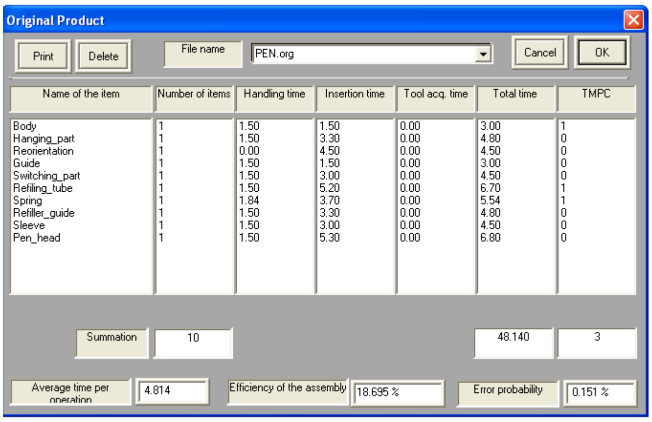


Figure (15) The original product of the ball pen assembly

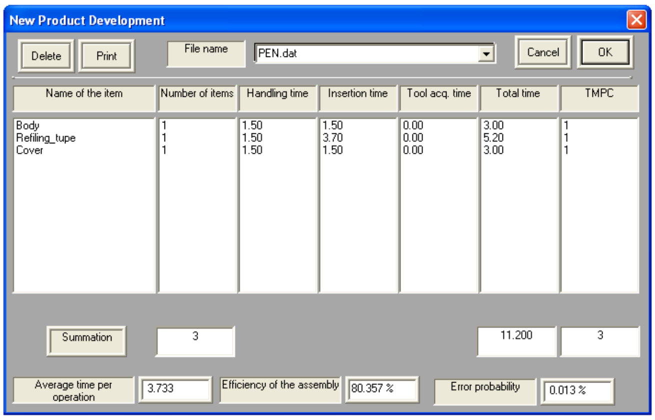


Figure (16) Program results of new design of the ball pen

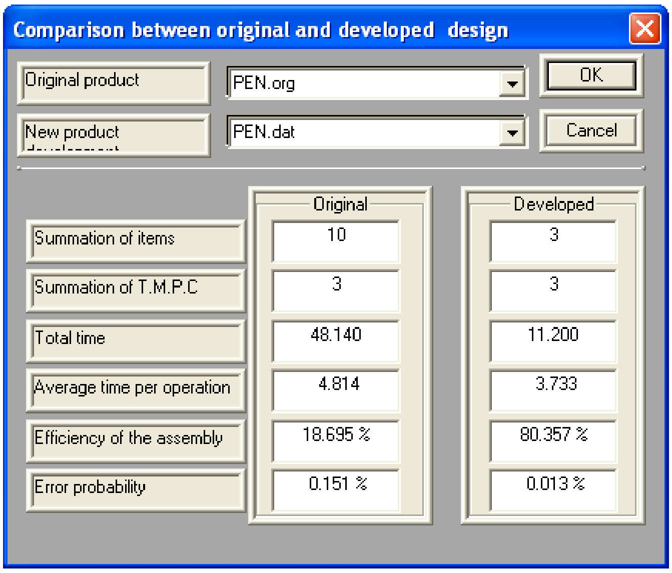


Figure (17) Results of comparisons between the original and modified design for the ball pen assembly as acquired from the developed DFA program

B. Design for Manufacturing

Two case studies are given in this section to demonstrate the capability and limitations of the developed DFM program, these case studies include: (a) The Bracket part, (figure 18) and an air conditioner fan part (figure 19).

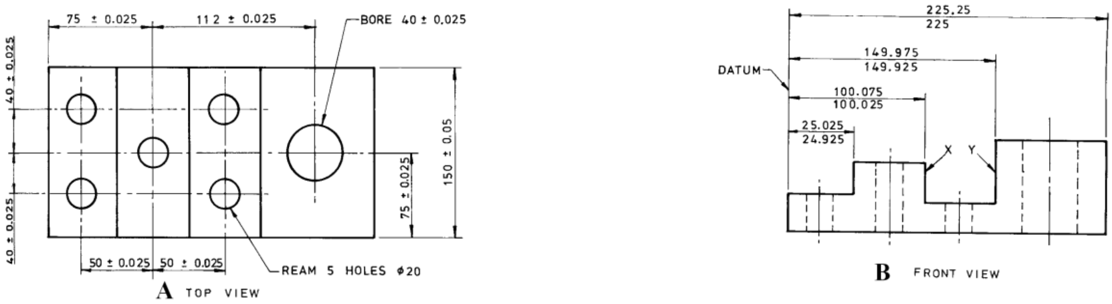


Figure (18) The bracket part. (a) Top view. (b) Front view.

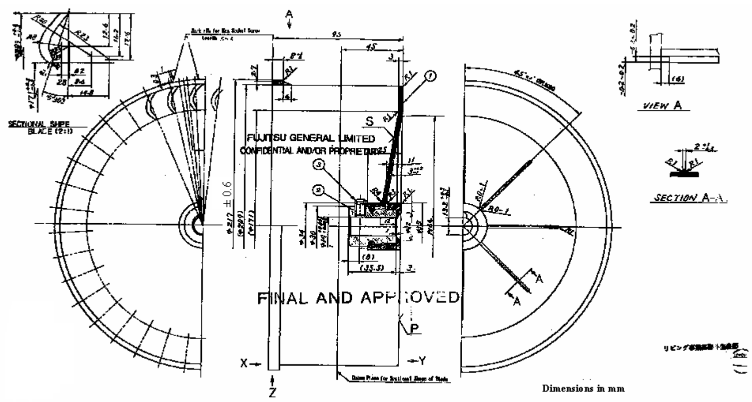


Figure (19) Air conditioner centrifugal fan design obtained from the State Company for Electrical Appliances – AL – Waszeria, Baghdad, Iraq

(B – 1) The Bracket Part: The bracket part that is used as a case study is taken from an engineering drawing, analyzed by its terms of shape attributes producing capabilities and applying it to the developed DFM program which gives the results presented in figure (20).

The DFM program displays the processes that are capable of achieving the shape attributes of the bracket part, figure (21). In this case the only option is by the machining process.

The DFM program then displays the capable processes of achieving the shape attributes using available materials, figure (22).

However by examining figure (20) carefully, it seems to be that the "no draft angle attribute" is the most likely obstacle that prevented the program to allocate other manufacturing process alternatives to this part. Hence if the designer adds a drafting angle to his design which may not affect the part functionality other manufacturing process alternatives will result, see figure (23).

Results of the re-design of the bracket widen the options for process selection that include (see figure (24)): sand casting, investment casting, die casting, injection molding, structure foam, closed die forging, machining, ECM, EDM sheet metal (stamping / bending) and thermoforming. Hence, the user may select a more economical operation from these.

The effective tolerance of the bracket was selected to be ± 0.025 mm. Using this tolerance as an input to the developed DFM program as shown in figure (25), showed that "machining" is the only capable process to produce the required design, whereas all other processes were excluded.

It is clear from the program results that the tolerance specified for the bracket is very strict, and imposing the fourth step in the tolerance step function [4], the grinding. This will impose 6 times the original cost compared with parts that has no strict tolerances. Therefore this will remind the designer to study the possibility of less strict tolerances to be used for this part.

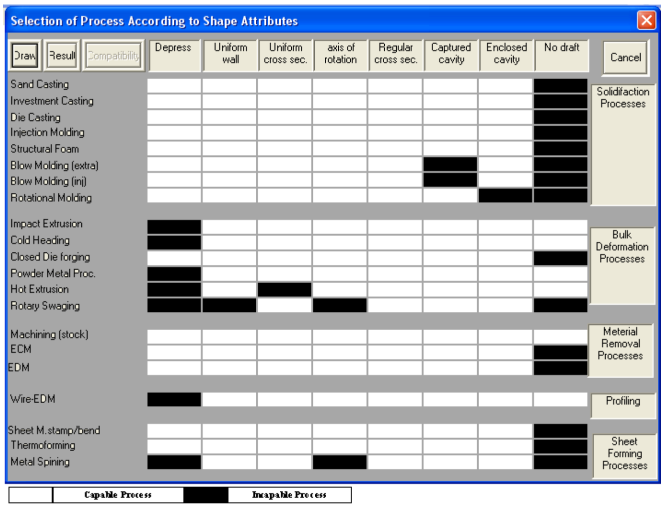


Figure (20) The capable and incapable processes for the shape attributes of the bracket part

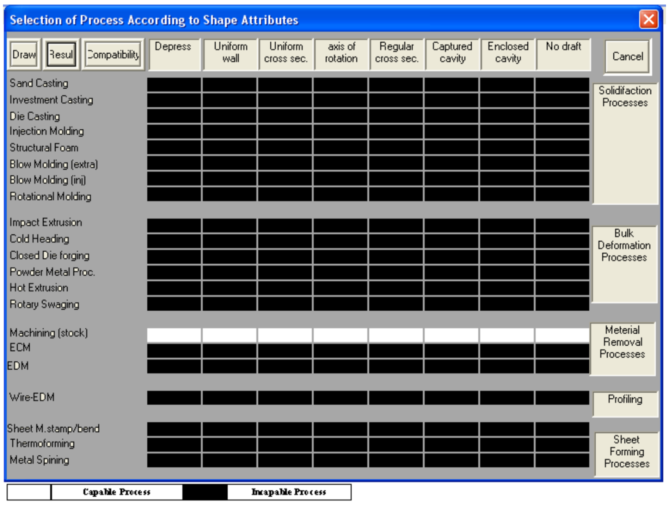


Figure (21) The capable processes for the shape attributes of the bracket part manufacturing

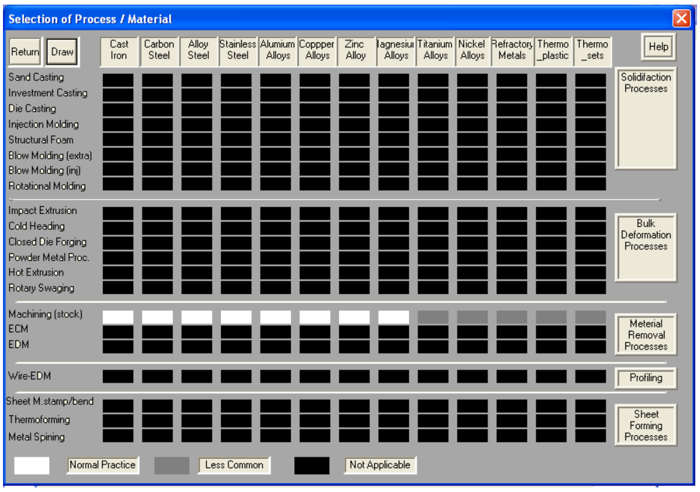


Figure (22) Results of compatibility between process and materials of the bracket part

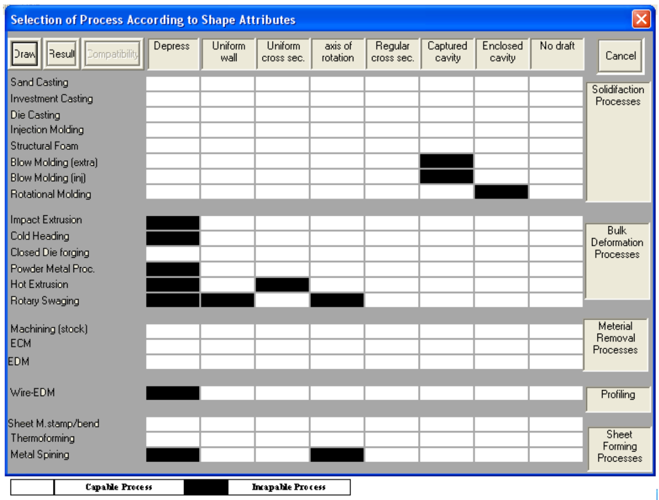


Figure (23) The capable and incapable processes for the shape attributes of the bracket part manufacturing applying "no draft angle attribute"

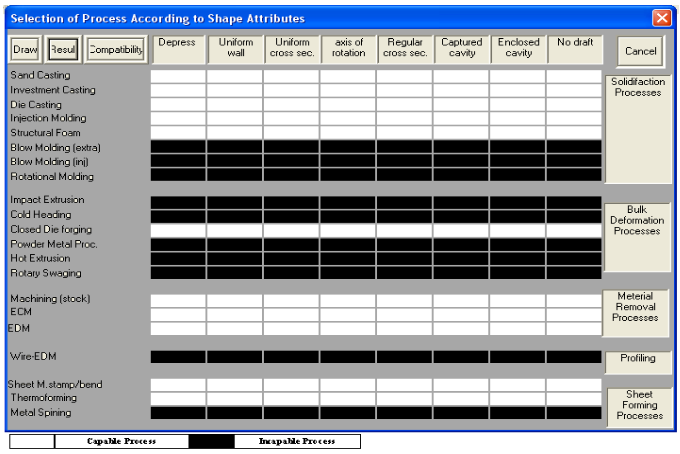


Figure (24) The capable processes for the shape attributes of the bracket part manufacturing applying "no draft angle attribute"

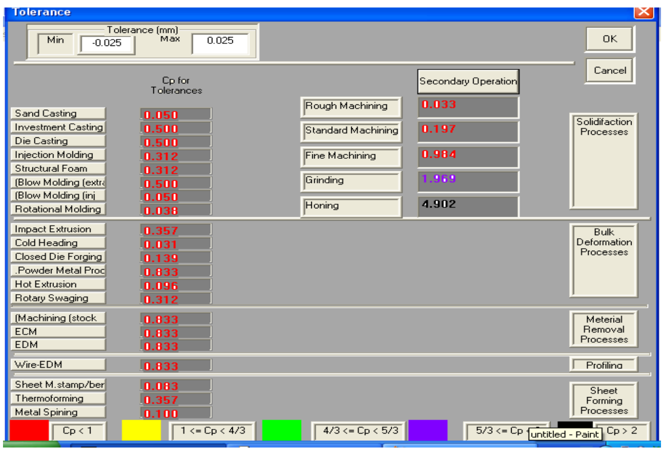


Figure (25) The tolerance process capability to the bracket

(B – 2) Air Conditioner Centrifugal Fan Case Study:

This part is selected from the production range of the State Company for Electrical Industries. One of the products produced in that company is air conditioner, and one of its parts is the centrifugal fan. The centrifugal fan is a plastic part made in injection molding; functionally, the fan must rotate and withstand the forces of the air wind speed, must rotate without vibration and must not hit the surrounding insulator.

The blade must keep its designed shape because it is responsible for air distribution equally in all directions, and that will not be happened exactly if there is any distortion in the blades shape. If the selected manufacturing process is incapable to produce the part to be within the design limits then, unbalanced forces will occur while the part functions, thus will introduce vibration and noise.

The outside diameter of the fan must be kept within its tolerances which is ± 0.6 mm. If the tolerance is over the limits the fan will hit the insulator surroundings and make damage or destroy it. If it is less than the limits the fan will not work properly.

The blade thickness is not uniform; it is less than 3 mm in one area and its bend have more than one arc.

The air conditioner manufactured in the company by patch quantity, the quantity may be about 300 product / patch. That leads to a quantity about 300 fan / patch.

Applying the shape attributes for the air conditioner centrifugal fan to the program gives the results presented in figure (26). The program identified the processes that are capable of achieving the shape attributes namely: sand casting, investment casting, die casting, injection molding, structural foam, closed die forging, machining form stock, ECM and EDM as shown in figure (27).

The program then displays the capable processes of achieving the shape attributes with its possible available materials as shown in figure (28).

The effective tolerance of the centrifugal fan is the tolerance added to the outside diameter which is 217 ± 0.6 mm. Implementing this range of values in the program gives the result shown in figure (29). This range of tolerance is liberal.

In this case study the processes that are identified to be capable of manufacturing the centrifugal fan, were examined one by one. It could be concluded that limitations of some of the stated processes make them infeasible to be adopted to manufacture the fan, hence they may be discarded, and these processes are: Sand Casting, Investment Casting, Structural Foam, Machining (from stock), ECM and EDM.

. The reason that the program identified these processes as valid alternatives is due to the incomplete database and product information available to the program, hence, future work to establish a more comprehensive database and further development of the program are suggested for future development.

According to the employed operation capability database, the three processes that can be used successfully to produce the fan regardless of its given material are: Die Casting, Closed Die Forging and Injection Molding. Both die casting and close die forging requires secondary operations.

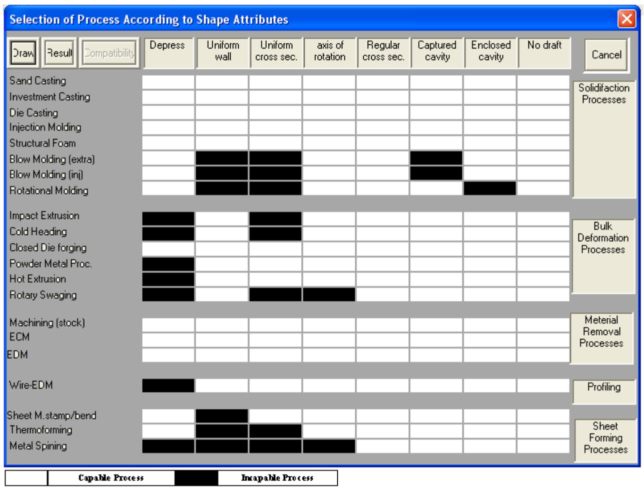


Figure (26) The capable and incapable processes for the shape attributes of the centrifugal fan

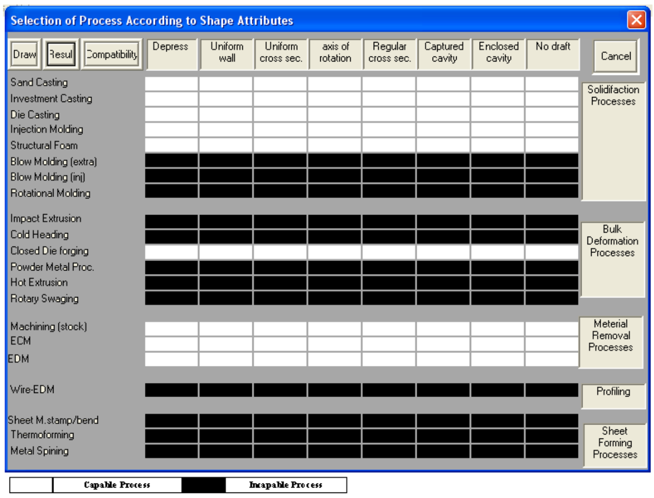


Figure (27) The capable processes for the shape attributes of air conditioner fan production as identified by the DFM program

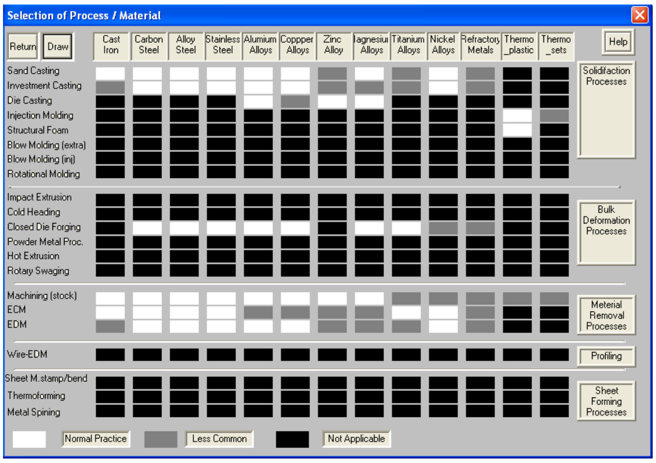


Figure (28) Compatibility between process and materials of the centrifugal fan

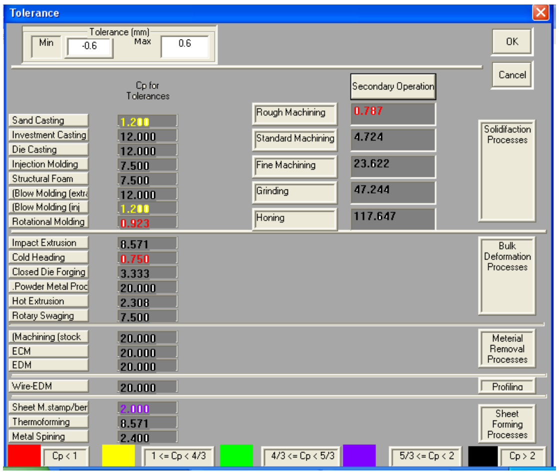


Figure (29) Tolerance process capability to the centrifugal fan

CONCLUSIONS

- The method adopted in the DFA gave very good enhancement in the efficiency of the assembly, which increased by 4 times, and error expectation probability increased by 84%.
- Verification of DFA program results and actual assembly of a conducted tests showed that the obtained results are close to each other when comparing the percentage of the design improvements, however, the actual resulting time values differs due to human and environment factors.
- The developed DFA method did not overlap with the usual work of the designer. It only gives support to the work to achieve the goal, therefore the DFA system can be implemented beneficially.
- In spite of good estimation that comes from DFA, the developed program still requires more developments and verification of its database to enable its commercial implementation in the industry.
- The adopted method of DFM succeeded to give valuable aid to the designer by reducing the many available alternatives to those which are capable to produce the part hence it will save time by reducing the possible rework time.

- The developed DFM program succeeded to give aid to the designer to select the appropriate material that is available in the required shape and form. In addition the program verifies whether the selected manufacturing process is capable to achieve the required tolerances, else it notifies the user that a secondary operation is required.
- Results of the case studies showed the importance of designing a draft angle where possible. This draft angle will help to extend the list of possible manufacturing process alternatives so that the user can select the best of these.
- Results of this paper showed that the way to automate the process of DFMA is still require more attention and further research specially to develop a full comprehensive database that covers all the variables affecting the process and integration the intelligence of the experts in the field. Therefore, to develop a comprehensive commercial and industrial system employing the DFMA more research work is needed. However, the step taken to reach the develop level of the DFMA program has contributed to this important field.

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ABBREVIATION

CE	Concurrent Engineering.
DFA	Design for Assembly.
DFM	Design for Manufacturing.
TMPC	Theoretical Minimum Part Count.
ECM	Electrochemical Machining.
EDM	Electrical Discharge Machining.