Studying the influence of Design for Assembly Method on Redesigning Desktop Punch

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Abstract

This paper builds on Boothroyd's and Dewhurst's assembly analysis method, investigating ways of simplifying and improving the efficiency of product assembly [1]. The desktop (hole) punch produced by ACCO's model A7074030 was examined for this work. Deploying the assembly analysis method in this context suggests an enhanced design for the desktop punch, which reduces assembly time, increases production efficiency, and reduces necessary components and parts. Autodesk Fusion 360 was used to draw the parts of the revised design, which were then assembled. After performing assembly analysis on both the preliminary and the revised designs, efficiency increased from 0.361 (preliminary) to 0.558 (revised), increasing design efficiency by 35.5%. Operation cost was reduced by 42.86% in this process. During this design revision, the number of components needed was reduced from 14 to 7, and the number of total parts required was reduced from 25 to 15. This paper concludes that the modified design is more user-friendly, efficient, and cost-effective—and that this kind of targeted product design process has broader potential to impact product design and economics. While manufacturing feasibility, operation cost, and scope limit study parameters, additional research employing this process with multiple products stand to address each of these issues.

Keywords
Design for Assembly, product design, assembly time

1. Introduction-

Product designs have often been altered for the purpose of making them user-friendly and/or adding functionality, but when it comes to the manufacturer's viewpoint product design is not always considered to the extent that it should be. For instance the ACCO's hole punch (model A7074030), examined in this research, involves unnecessary parts and assembly time, which negatively impacts overall design and economic efficiency. Assembling is one of the major costs of manufacturing; it takes time as different parts, manufactured within and outside plants, are constructed and assembled. It follows that issues relating to logistics and inventory costs are also negatively impacted, because of the time, location, and manufacturing issues related to assembly. Consequently, it might be valuable to reduce the number of necessary parts for any given product, and thus potentially reduce the assembly time and cost for that product. This paper contributes to this consideration by presenting a concept for improving overall production and assembly efficiency in the production line. An alternative design is suggested for a particular product (ACCO's desktop punch), and its production process is analyzed, producing an effective method for design change that will reduce assembly time, resulting in the reduction of total cost.

1.2 Research Objectives

The main purpose of this research is to test the influence of DFA on redesigning the desktop punch. To perform this test, the Boothroyd and Dewhurst method has been used to calculate assembly time and efficiency of design, both before and after redesigning the part [1].

The main objective of this research was to redesign the desktop punch, according to the below-mentioned goals:

1. To make the desktop punch more user-friendly
2. To minimize assembly time
3. To reduce the parts and components number
4. To increase design efficiency
5. To reduce manufacturing cost (and increase throughput)

2. Literature Review

Product design across industries and disciplines frequently undergoes change. In this process, the primary objective for design modifications is changing the design itself in order to streamline production. In Boothroyd-Dewhurst's (B&D) explanation of Design for Manufacture and Assembly (DFMA), the authors discuss the benefits of using DFMA by world-class manufacturers, and how DFMA will reduce the time of assembly and increase design efficiency[1], [2]. The Boothroyd-Dewhurst method was used in analyzing a case study of pedestrian traffic lights from PPK Technology Sdn Bhd, to enhance the design and reduce the manufacturing cost of a traffic light. As a result of this case study, the assembly time decreased from 758.45 seconds, to 318.80 seconds per product, and the assembly cost was reduced from RM1175.60 to RM207.20 [3]. The significance of Design for Assembly (DFA) and Design for Test (DFT) has also been discussed in the field of manufacturing compact medical electronic products [4]. In addition, the aerospace industry employed DFMA for using composites of carbon fiber reinforced plastics (CFRP) in manufacturing aircraft structures, to reduce the time and cost of assembly [5]. More generally, the DFA method has been used to generate optimal feasible assemble sequence by trying all the assembly combination sequences from the obtained feasible assembly; these sequences have been generated by using a simulated annealing technique [6].

In other fields, modified topology was made by generalizing the DFA concept, by considering four main principles (material properties of, relative motion between, contact between, and functionality of the parts). This modified topology was implemented on several industrial products to reduce the part numbers and showed successful results [7]. Similarly, energy-saving lamp design was developed through use of a light emitted diode (LED) to illuminate the whole house. This energy-saving lamp design was developed by obtaining DFMA, and the results showed an increase in design efficiency of 39.76% and a decrease in material cost of 8.54% [8]. Concurrently, methodology was introduced for systematic alternative consideration of design for assembly (DFA) and disassembly (DFD). This methodology was proposed to improve product design in the field of manufacturing [9].

Production and design frameworks are central to each of these processes, and it is notable that investigation on the impact industry 4.0 principles has been made by using the specific framework to enhance the assembly and design of products [10]. Prefabricated building design was investigated by DFMA and combined with parametric design to initiate a concept of DFMA-oriented parametric design [11] . Meanwhile, an integral approach has been developed for packaging design to generate restrictions for optimization model during created integrated DFA guidelines [12]. A more recent approach has been presented and implemented based on DFA agile manufacturing, by using data mining (DM) methods. Results in this case, showed there is a way to conduct cost estimation by using advanced data mining. This greatly impacts a designer's ability to perform cost/benefit analysis within the redesign process [13]. In order, to reduce the number of components for assembly during redesign, three main straightforward evolutions were developed. These are: components elimination, components combinations, and components elimination or recombination. These three DFA techniques are applied throughout manufacturing industries [14].

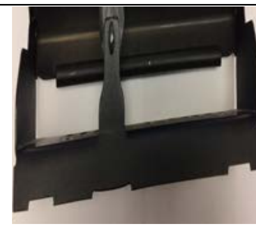
Assisting in these processes, Computer-based DFA software has been developed to support a specific assembly sequence model. A CAD model was then developed from this sequence [15]. Design principles are presented in this system to increase the influence of DFA. These principles, in turn, affect assembly sequence to reduce the time of assembly [16]. This paper adopts and builds upon these principles, proposing a new design for ACCO's desktop punch to reduce the product parts number and increase the assembly efficiency, thereby improving the overall product efficiency and validating previous scholarship.

3. Case Study on DFA

A desktop punch is used in both homes and offices to punch collated paper. Its use is intuitive to the user. The body of a desktop punch should be neither heavy, nor brittle. This paper considers ACCO's desktop punch (model A7074030) for the study. The various parts of the desktop punch, the part IDs, and the number of units required to construct the desktop punch have been shown below, in Table 1.

Table 1: Different parts of original design with their picture, identification number, and count.

Part Name	Part Picture	Part ID	Number of Units	Part Name	Part Picture	Part ID	Number of Units
Screw		1	3	Stand rivet		8	1
Circlip for punch		2	3	Lever stand		9	1
Spring		3	3	Impact dumper		10	1
Punch		4	3	Rivet for pusher		11	2
Punch Holder		5	3	Pusher		12	1

Lever rivet		6	1	Clip tray		13	1
Push lever		7	1	Base		14	1

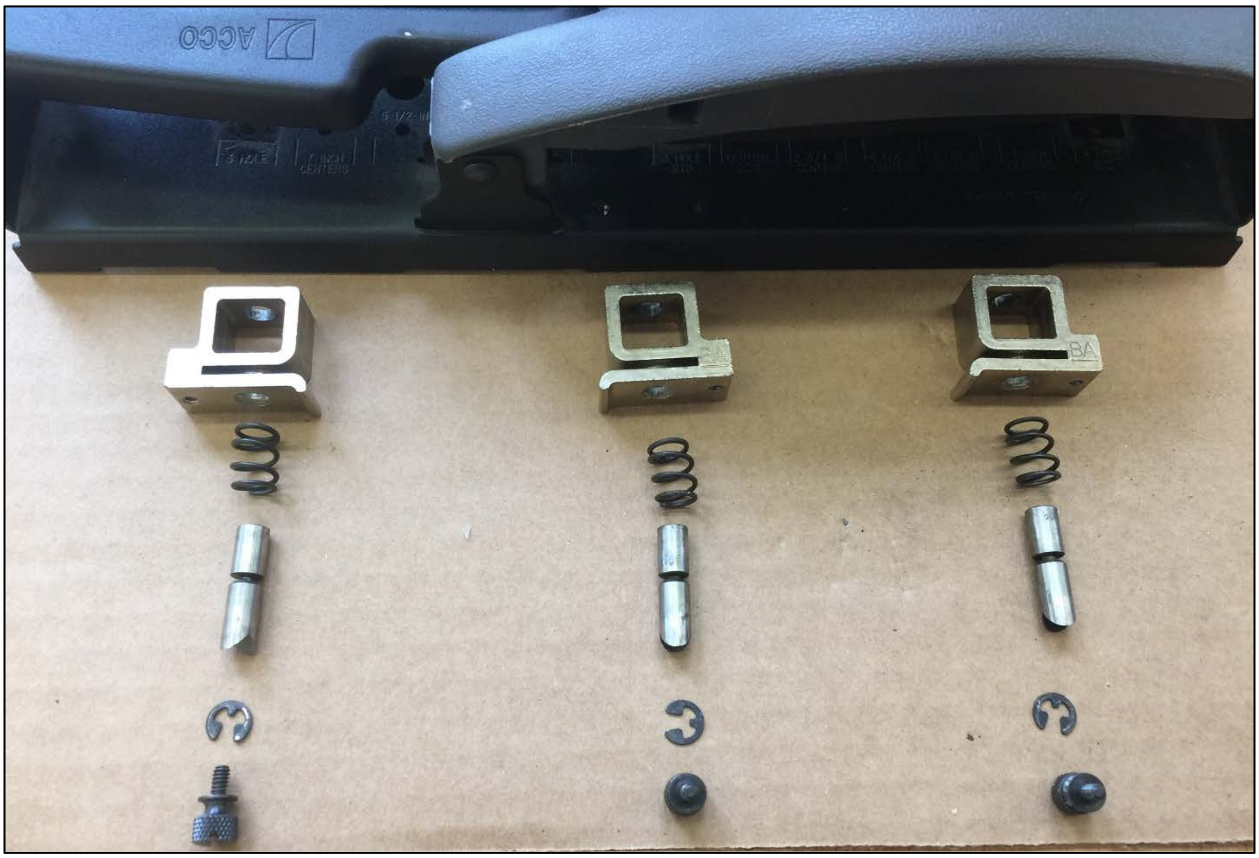


Figure 1: Different parts of desktop assembly.

The preliminary design for this desktop punch has 14 components and includes 25 parts. The main focus of the methodological work in this paper seeks to reduce the number of the components and parts, increasing the ease of desktop punch use and assembly.

4. Methodology

This paper considers redesigning the desktop punch in order to reduce final assembly time and manufacturing cost. The proposed redesign is based on the author's understanding of mechanics and perception that the original design is unnecessarily complicated. Assembly time for the original design and this paper's proposed design were calculated using the method developed by Boothroyd and Dewhurst, as discussed in Appendix A [2]. This methodology was executed in two steps; first, modifying the design of the desktop punch and second, calculating and comparing the assembly time and design efficiency between the preliminary design and the suggested design.

4.1 Design Modifications

In order to reduce the number of needed desktop punch parts and make it easier to assemble, the following design modifications were performed on its preliminary design. Then, these modifications were translated to CAD models by utilizing Autodesk Fusion 360.

1. To eliminate the clip tray and change the design of the base so that it could be directly placed on a trash receptacle, allowing the waste to be removed without clip tray. This will require some changes to the design of the punch base. The new base is shown in Figure 2. All, the parts for new designs were drawn in Autodesk Fusion 360.

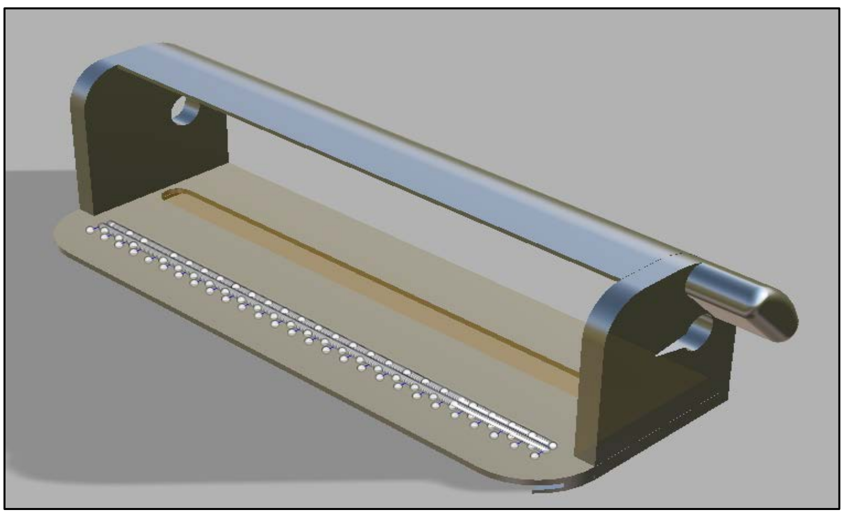


Figure 2: The revised design for the base of desktop punch.

The design in Figure 2 allows for use without a clip tray, enabling direct garbage can placement by using the two guides underneath the base.

2. Next, making a snap fit for punch holder eases the assembling process and this way, the screws that were earlier required to assemble the punch holder, can also be eliminated. The punch holder has been designed in a way that allows punch holders to slide and snap in place, depending on the desired distances between holes. This adds substantial flexibility to potential distances between the holes of punches. The new punch holder design is shown in Figure 3.

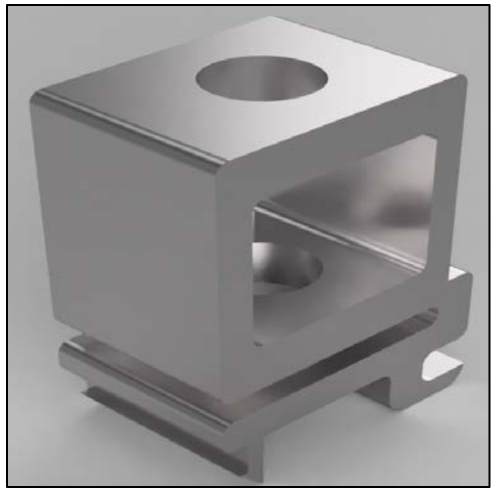


Figure 3: The revised design for punch holder.

3. Then, the revised design incorporates a handle that performs as both lever and pusher. This means that all the original lever parts (like stand, rivets, pusher with a handle. and an external circlip) can be eliminated. The design for the revised handle is shown in Figure 4.

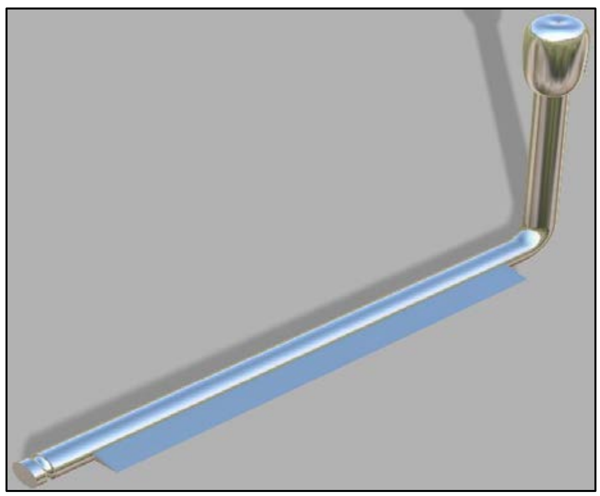


Figure 4: Proposed handle design for the revised desktop punch design.

4. The other parts of the revised design are shown in Figures 5-8. Figure 5 shows the external circlip design that would be required to connect the handle with the base, and this part was not required in the original design. Figure 6 shows the E-type circlip design to hold the punch in the revised design, this is same as the one required in the original design. Figures 7 and 8 show the design for punch and spring respectively, for the punch holder sub-assembly to be used in the revised desktop punch, and they were also present in the original design.

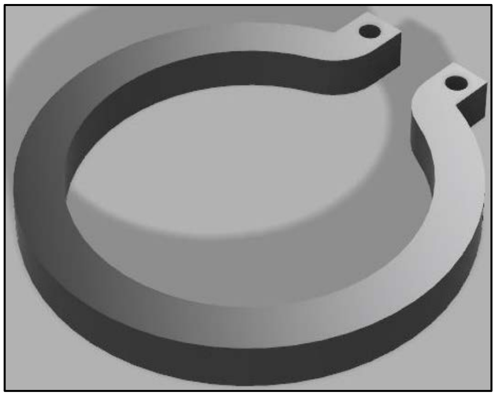


Figure 5: Proposed external circlip design to connect handle in the revised design

Figure 6: E-type circlip design for punch holder sub-assembly

Figure 7: Punch for the punch holder sub-assembly

Figure 8: Spring for the punch holder sub-assembly

Figure 9 presents all the parts to be assembled for the final revised design. The new design seems better as it would be less complicated, requires fewer components and parts, and is more easily assembled (without need for complex instructions or advanced tools). There are no screws and rivets involved in the new design. It follows that assembling and dismantling of the new design will be easier as compared to assembling and dismantling of the original design.

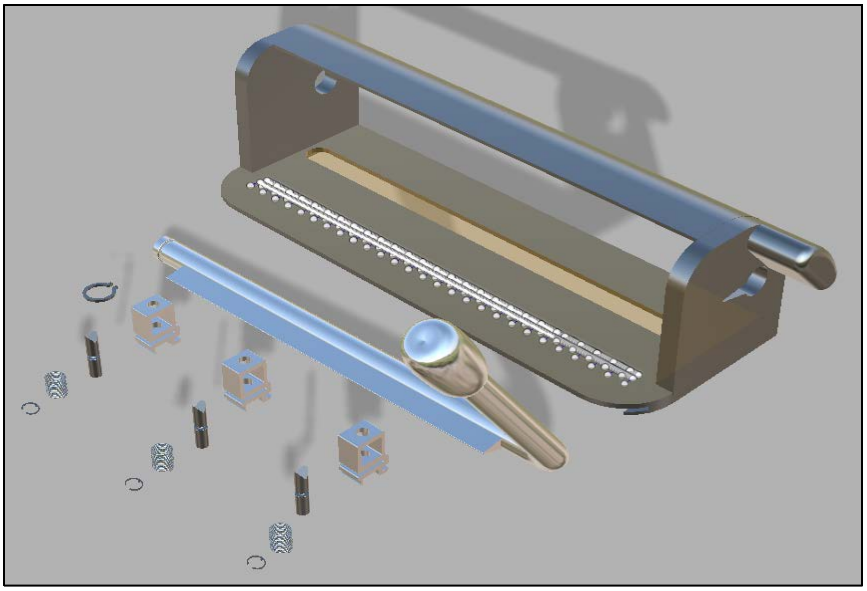


Figure 9: Revised design before assembly

Finally, all the components and parts of the modified desktop punch are assembled by use of Autodesk Fusion 360. Figure 10 below, shows the configuration of the revised desktop punch. It can be observed from figure 10 that the final modified product of desktop punch is more easily assembled than the preliminary one, and integrates greater flexibility for adjusting the punch holders to any preferred distances between the holes (within the limits of the base track). The revised one-piece handle simplifies assembly and improves potential functionality. It is also worth mentioning that is easy to reduce or increase the number of holes produced by adding or removing punch holders.

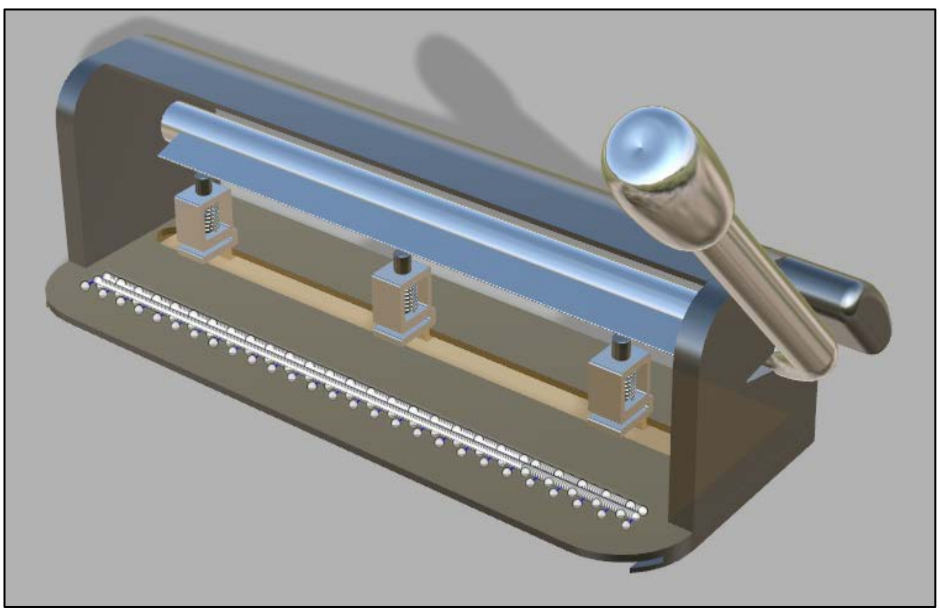


Figure 10: Revised design final assembled of redesigned desktop punch

4.2 Calculating the assembly time and design efficiency

This section discusses how the above methodology has been used for the case of a desktop punch model and below is a description of various column headings, and in the parenthesis the corresponding number are presented for the heading in Tables 2 and 3. The ID (1) presents the numerical identification number given to each part. Count (2) is the number of units of the part. Handling code (3) is the code given in Appendix I. This code was decided after considering the methodology given by Boothroyd and Dewhurst [1]. The corresponding handling time (4) was considered from Appendix I. Manual handling, α-symmetry, β-symmetry, thickness and length were the factors for each part that were considered while using Appendix I. Similarly, the insertion code (5) and insertion time (6) was taken from Appendix II after considering the methodology for insertion. Operation time (7) is the sum of handling time and insertion time. Operations cost (8) was considered in cents is a linear factor of operation time with a coefficient of 0.4, implying that for every second in the assembly work the cost is $0.04. Table 3 shows the worksheet analyzing the desktop punch's old design, using the Boothroyd and Dewhurst [1] method. The equation (1), in Appendix A, has been used to calculate design efficiency. Part required (9) was calculated by considering the theoretical minimum parts and asking questions (Q1), (Q2) and (Q3) from the methodology section.

The screw from original design was given the IDs 1 and 3, which were required for assembly. As it has one axis of insertion and needs end-to-end rotation, so $\alpha = 360°$, and it can be inserted from anywhere considering its own axis of insertion (and therefore $\beta = 0°$). Now, this screw could be manually handled with one hand, therefore the functional presence of one hand is considered in Appendix I. Also $\alpha + \beta = 360°$, thus leading us to the second row. Since the screw is easy to grasp and manipulate, and its thickness is less than 2 mm, (but the size is between 6 mm and 15 mm), the handling code for the screw will be 11 and the estimated handling time for assembly will be 1.8s. This means the screw can be secured immediately after insertion. Also, the screw and hand can easily reach the desired location, and (if needed) a tool can be operated easily. The screw tightens immediately after insertion and it is easy to align and position with no torsional resistance, therefore the manual insertion code is 38 and insertion time is 6s were considered. In a similar manner, the handling and insertion times for all the parts and sub-assemblies were found for both the original and revised designs.

Table 2: Worksheet for assembly of desktop punch's original design

Part name	1	2	3	4	5	6	7	8	9
	ID	Count	Handling Code	Handling Time (sec)	Insertion Code	Insertion Time (sec)	Operation Time (sec)	Operation Cost (¢)	Part Required
Screw	1	3	11	1.8	38	6	23.4	9.36	0
Circlip for punch	2	3	42	4.35	41	7.5	35.55	14.22	3
Punch	3	3	10	1.5	00	1.5	9	3.6	3
Spring	4	3	10	1.5	00	1.5	9	3.6	3
Punch holder	5	3	30	1.95	00	1.5	10.35	4.14	3
Lever rivet	6	1	0,0	1.13	30	2	3.13	1.252	0
lever	7	1	3,0	1.95	06	5.5	7.45	2.98	1
Stand rivet	8	1	1,1	1.8	41	7.5	9.3	3.72	0
Lever stand	9	1	0,0	1.13	06	5.5	6.63	2.652	0
impact dumper	10	1	0,0	1.13	35	7	8.13	3.252	0
Rivet for pusher	11	2	1,1	1.8	30	2	7.6	3.04	2
Pusher	12	1	3,0	1.95	30	2	3.95	1.58	1

Clip tray	13	1	2,0	1.8	30	2	3.8	1.52	0
Base	14	1	3,0	1.95	30	2	3.95	1.58	1
							141.24	56.496	17
							TM	CM	NM
						Design Efficiency		0.361	

The design efficiency for the original design was found to be 0.361. After a thorough discussion, there were many design revisions considered, from the aspect that the functionality of the desktop punch should not be compromised. Further, it was determined that the new design should be easy to explain and easily understood.

The worksheet for analyzing the desktop punch's revised design is shown in Table 3. This table also presents various integral factors including handling, insertion, and operation times, as well as operation cost and part required. Operation cost is assumed to be a factor of operation time (in seconds), making the cost of operation for each second $0.04.

Table 3: Worksheet for assembly of desktop punch's revised design

	1	2	3	4	5	6	7	8	9
Part name	ID	Count	Handling Code	Handling Time (sec)	Insertion Code	Insertion Time (sec)	Operation Time (sec)	Operation Cost (¢)	Part Required
Punch holder	1	3	30	1.95	00	1.5	10.35	4.14	3
E type circlip lock ring	2	3	42	4.35	41	7.5	35.55	14.22	3
Punch	3	3	10	1.5	00	1.5	9	3.6	3
Spring	4	3	10	1.5	00	1.5	9	3.6	3
External Circlips	5	1	4,2	4.35	31	5	9.35	3.74	1
Handle	6	1	1,0	1.5	30	2	3.5	1.4	1
Base	7	1	3,0	1.95	30	2	3.95	1.58	1
							80.7	32.28	15
							TM	CM	NM
						Design Efficiency		0.558	

5. Conclusion and Limitations

Assembly is one of the most important processes that are required in the manufacturing industry. This paper studies the assembly time and design efficiency for a desktop punch and tries to improve that, with the help of the method proposed by Boothroyd and Dewhurst [1]. The new revised design is more user-friendly, especially through elimination of the base cover. That will make using the hole punch more flexible. Another benefit of this revised design its integrated hole variability, because the punch holder can move freely on the base guide, by using the snap fit of the punch holder and eliminating the fixed screw from the previous design. When comparing the previous design and the revised design, design efficiency increased from 0.361 to 0.558, a marked improvement of 35.5%. Operation time and cost were reduced by 42.86% and 42.86% respectively. According to this data, minimizing the number of components and parts in the manufacturing processes has a corollary reduction in the cost required to produce the desktop punch. In this process, the amount of raw materials required to produce the modified desktop punch is likewise reduced. The revised design only requires one simplified lever (which can be used by a single hand), to press all the three punches, with no additional part required to connect the handle to the punches. The number of punches in the holder can also be reduced or increased easily, by removing or adding punch holders to the base guide. This creates more flexibility for reducing or increasing the number of holes with relative ease.

The assembly of parts and sub-assemblies in the hole punch's original design was a cumbersome, and the revised design is more easily assembled and dismantled. The revised design also reduces the number of required parts from 25 to 15, and components from 14 to 7, respectively. If the proposed revised design is to be manufactured, the manufacturers could use the same spring and E-type circlips used in the old design, but they would have to construct the newly designed handle, punches, external circlips, base and snap fit punch holders.

The new design does not consider the manufacturing feasibility and its aftermath on the overall cost, and this is one limitation of the design. Another assumption is that operation cost has been considered as a linear factor of operation time, and that for each second of operation time the corresponding operation cost is $ 0.04. More work and analysis should be performed on sub-assembly components. According to the preliminary analysis performed by the researcher, the sub-assembly components have significant effect on reducing assembly time and increasing design efficiency. A piece of rubber should be placed on the base punch guide to prevent the punch holders from easily sliding on the guide during the punching process, causing potential errors in the required distances between the holes.

6. Acknowledgements

The authors wish to thank the resources of Department of Industrial and Management Systems Engineering, West Virginia University.

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Appendix

Appendix A

Boothroyd and Dewhurst [2] compared the "ideal" assembly time with an estimated "actual" time. Ideal assembly time was calculated for the theoretical minimum number of parts, by asking the following questions:

Does the part have to **move** relative to all other parts already assembled? (Q1)
Must the part be of a **different material** than or isolated from the other parts assembled? (Q2)
Must the part be **separate** from all other parts because of assembly or disassembly requirements. (Q3)

If the answer to any of the above questions is "yes", the number of parts is entered into the calculation; otherwise a "zero" is assigned. The theoretical minimum number of parts (NM) is the sum of the numbers assigned to each part in the assembly. The theoretical assembly time is assumed to be 3 seconds. The assumption is based on the notion that an ideal part is easy to grasp, requires no particular orientation and easy to assemble. The design efficiency is the ratio of the theoretical minimum assembly time (3 x NM) to an estimate of the actual assembly time (TM) has been mentioned below as equation (1).

$$\text{Design Efficiency} = \frac{3\ X\ NM}{TM} \quad \ldots\ldots\ldots (1)$$

Important definitions:

Manual handling – The grasping, transportation and orientation of parts/sub-assemblies before they are added to work fixture.
α–Symmetry - The rotation symmetry of a part about an axis perpendicular to the axis of insertion.

For parts with one axis of insertion, end-to-end orientation is necessary when α = 360°; otherwise α = 180°.
β-Symmetry – The rotational symmetry of a part about its axis of insertion; or equivalently about an axis which is perpendicular to the surface on which the part is placed during assembly. The magnitude of rotational symmetry is the smallest angle through which the part can be rotated and repeat its orientation.
Thickness – The length of the shortest side of the smallest rectangular prism which encloses the part. However, if the part is a cylindrical part, or has a regular polygonal cross-section with five or more sides, and the diameter is less than the length, then thickness is defined as the radius of the smallest cylinder which can enclose the part.
Size – The length of the longest side of the smallest rectangular prism that can enclose the part.

There are some other terms that are used to describe different conditions of parts due to magnetic force, grease, coating, slippery, require careful handling, etc. These parts have been described in Table I with the part condition and their description.

Table A1: Part handling conditions and corresponding description.

S. No.	Part(s) Condition	Description
1	Nest/Tangle	Simple manipulation of a single part, ex. Taper cups, closed-end helical springs, circlips, etc
2	Stick	Slip from fingers or grasping tools because of their shape/surface conditions
3	Careful handling	Fragile or delicate, have sharp corners/edges, or present other hazards to the operator
4	Severely Nest/ Tangle	Interlock when in bulk and both hands are needed to apply a separation force or achieve specific orientation to separate
5	Flexible parts	Substantially deformed parts during manipulation and necessitate use of 2 hands

The charts given in the Appendix I and II deals with the part handling time and part insertion time respectively. They present the time in seconds and actual assembly time is the sum of part handling time and part insertion time. The additional conditions that one will come around while finding insertion time are stated in the below six points [1].

1. A part is the solid or non-solid element of an assembly process. A sub-assembly is considered a part if it is added during assembly. However, adhesives, fluxes, fillers, etc. used for joining parts
2. is not considered to be parts.

3. Obstructed access means that the space available for the assembly operation causes a significant increase in the assembly time. Restricted vision means that the operator must rely mainly on tactile sensing during the assembly process.

4. Holding down required, means that the part is unstable after placement or insertion or during subsequent operations and will require gripping, realignment or holding down before it is finally secured. Holding down refers to an operation that if necessary, maintains the position and orientation of a part already in place, prior to, or during the next assembly operation. A part is located if it will not require holding down or realignment for subsequent operations and is only partially secured.

5. A part is easy to align and position if the position of the part is established by locating features on the part or on its mating part and insertion is facilitated by well design chamfers or similar features.

6. The resistance encountered during part insertion can be due to: small clearances, jamming or wedging, hang-up conditions or insertion against a large force. For example, a press fit is an interference fit where a large

force is required for assembly. The resistance encountered with self-tapping screws is similarly an example of insertion resistance.

7. The standard time for screw tightening includes the additional time to pick up a power tool, run down the screw or nut, and release the tool. If several screws are to be inserted and/or tightened consecutively then a more accurate calculation for Column 7 of the worksheet is
8. **(2)** x **[(4)** + **(6) -3]** + 3 where (2), (4) and (6) are the numbers in Columns 2, 4 and 6 respectively.

Appendix B

Table B1: MANUAL HANDLING- ESTIMATED TIMES (seconds)

MANUAL HANDLING — ESTIMATED TIMES (seconds)

Key: ONE HAND

parts can be grasped and manipulated by one hand without the aid of grasping tools

		parts are easy to grasp and manipulate					parts present handling difficulties (1)				
		thickness > 2 mm			thickness ≤ 2 mm		thickness > 2 mm			thickness ≤ 2 mm	
		size >15 mm	6 mm ≤ size ≤15 mm	size <6 mm	size >6 mm	size ≤6 mm	size >15 mm	6 mm ≤ size ≤15 mm	size <6 mm	size >6 mm	size ≤6 mm
		0	1	2	3	4	5	6	7	8	9
$(\alpha+\beta) < 360°$	0	1.13	1.43	1.88	1.69	2.18	1.84	2.17	2.65	2.45	2.98
$360° \le (\alpha+\beta) < 540°$	1	1.5	1.8	2.25	2.06	2.55	2.25	2.57	3.06	3	3.38
$540° \le (\alpha+\beta) < 720°$	2	1.8	2.1	2.55	2.36	2.85	2.57	2.9	3.38	3.18	3.7
$(\alpha+\beta) = 720°$	3	1.95	2.25	2.7	2.51	3	2.73	3.06	3.55	3.34	4

ONE HAND with GRASPING AIDS

parts can be grasped and manipulated by one hand but only with the use of grasping tools

			parts need tweezers for grasping and manipulation								parts need standard tools other than tweezers	parts need special tools for grasping and manipulation
			parts can be manipulated without optical magnification				parts require optical magnification for manipulation					
			parts are easy to grasp and manipulate		parts present handling difficulties (1)		parts are easy to grasp and manipulate		parts present handling difficulties (1)			
			thickness > 0.25 mm	thickness ≤ 0.25 mm	thickness > 0.25 mm	thickness ≤ 0.25 mm	thickness > 0.25 mm	thickness ≤ 0.25 mm	thickness > 0.25 mm	thickness ≤ 0.25 mm		
			0	1	2	3	4	5	6	7	8	9
$\alpha \le 180°$	$0 \le \beta \le 180°$	4	3.6	6.85	4.35	7.6	5.6	8.35	6.35	8.6	7	7
$\alpha \le 180°$	$\beta = 360°$	5	4	7.25	4.75	8	6	8.75	6.75	9	8	8
$\alpha = 360°$	$0 \le \beta \le 180°$	6	4.8	8.05	5.55	8.8	6.8	9.55	7.55	9.8	8	9
$\alpha = 360°$	$\beta = 360°$	7	5.1	8.35	5.85	9.1	7.1	9.55	7.85	10.1	9	10

TWO HANDS for MANIPULATION

		parts present no additional handling difficulties					parts present additional handling difficulties (e.g. sticky, delicate, slippery, etc.) (1)				
		$\alpha \le 180°$			$\alpha = 360°$		$\alpha \le 180°$			$\alpha = 360°$	
		size > 15 mm	6 mm ≤ size ≤ 15 mm	size < 6 mm	size > 6 mm	size ≤ 6 mm	size > 15 mm	6 mm ≤ size ≤ 15 mm	size < 6 mm	size > 6 mm	size ≤ 6 mm
		0	1	2	3	4	5	6	7	8	9
parts severely nest or tangle or are flexible but can be grasped and lifted by one hand (with the use of grasping tools if necessary) (2)	8	4.1	4.5	5.1	5.6	6.75	5	5.25	5.85	6.35	7

TWO HANDS required for LARGE SIZE

		parts can be handled by one person without mechanical assistance									parts need special tools for grasping and manipulation
		parts do not severely nest or tangle and are not flexible								parts severely nest or tangle or are flexible (2)	
		part weight < 10 lb				parts are heavy (> 10 lb)					
		parts are easy to grasp and manipulate		parts present other handling difficulties (1)		parts are easy to grasp and manipulate		parts present other handling difficulties (1)			
		$\alpha \le 180°$	$\alpha = 360°$	$\alpha \le 180°$	$\alpha = 360°$	$\alpha \le 180°$	$\alpha = 360°$	$\alpha \le 180°$	$\alpha = 360°$		
		0	1	2	3	4	5	6	7	8	9
two hands required for grasping and transporting parts	9	2	3	2	3	3	4	4	5	7	9

CHART . -1

Table B2: MANUAL INSERTION- ESTIMATED TIMES (seconds)

MANUAL INSERTION—ESTIMATED TIMES (seconds)

Key:

- PART ADDED but NOT SECURED
- PART SECURED IMMEDIATELY
- SEPARATE OPERATION

Part added but not secured

		after assembly no holding down required to maintain orientation and location (3)				holding down required during subsequent processes to maintain orientation or location (3)			
		easy to align and position during assembly (4)		not easy to align or position during assembly		easy to align and position during assembly (4)		not easy to align or position during assembly	
		no resistance to insertion	resistance to insertion (5)	no resistance to insertion	resistance to insertion (5)	no resistance to insertion	resistance to insertion (5)	no resistance to insertion	resistance to insertion (5)
		0	1	2	3	6	7	8	9
addition of any part (1) where neither the part itself nor any other part is finally secured immediately: part and associated tool (including hands) can easily reach the desired location	0	1.5	2.5	2.5	3.5	5.5	6.5	6.5	7.5
part and associated tool (including hands) cannot easily reach the desired location: due to obstructed-access or restricted vision (2)	1	4	5	5	6	8	9	9	10
part and associated tool (including hands) cannot easily reach the desired location: due to obstructed access and restricted vision (2)	2	5.5	6.5	6.5	7.5	9.5	10.5	10.5	11.5

Part secured immediately

		no screwing operation or plastic deformation immediately after insertion (snap/press fits, circlips, spire nuts, etc.)		plastic deformation immediately after insertion						screw tightening immediately after insertion (6)	
				plastic bending or torsion			rivetting or similar operation				
					not easy to align or position during assembly			not easy to align or position during assembly			
		easy to align and position with no resistance to insertion (4)	not easy to align or position during assembly and/or resistance to insertion (5)	easy to align and position during assembly (4)	no resistance to insertion	resistance to insertion (5)	easy to align and position during assembly (4)	no resistance to insertion	resistance to insertion (5)	easy to align and position with no torsional resistance (4)	not easy to align or position and/or torsional resistance (5)
		0	1	2	3	4	5	6	7	8	9
addition of any part (1) where the part itself and/or other parts are being finally secured immediately: part and associated tool (including hands) can easily reach the desired location and the tool can be operated easily	3	2	5	4	5	6	7	8	9	6	8
part and associated tool (including hands) cannot easily reach desired location or tool cannot be operated easily: due to obstructed access or restricted vision (2)	4	4.5	7.5	6.5	7.5	8.5	9.5	10.5	11.5	8.5	10.5
part and associated tool (including hands) cannot easily reach desired location or tool cannot be operated easily: due to obstructed access and restricted vision (2)	5	6	9	8	9	10	11	12	13	10	12

Separate operation

		mechanical fastening processes (part(s) already in place but not secured immediately after insertion)				non-mechanical fastening processes (part(s) already in place but not secured immediately after insertion)				non-fastening processes	
		none or localized plastic deformation				metallurgical processes					
							additional material required				
		bending or similar processes	rivetting or similar processes	screw tightening (6) or other processes	snap fit, snap clip, press fit, etc.	no additional material required (e.g. resistance, friction welding, etc.)	soldering processes	weld/braze processes	chemical processes (e.g. adhesive bonding, etc.)	manipulation of parts or sub-assembly (e.g. orienting, fitting or adjustment of part(s), etc.)	other processes (e.g. liquid insertion, etc.)
		0	1	2	3	4	5	6	7	8	9
assembly processes where all solid parts are in place	9	4	7	5	3.5	7	8	12	12	9	12

CHART 2

Biography

Omar Al-Shebeeb is PhD candidate student of Industrial and Management Systems Engineering (IMSE) at West Virginia University (WVU) and Graduate Teaching Assistant in the Manufacturing Lab of Industrial Engineering department for three years. Omar Al-Shebeeb obtained his B.E degree in Production Engineering from the Production Engineering Department at University of Technology, Baghdad, Iraq, M.S. degree in Production Engineering from the Production Engineering Department at University of Technology, Baghdad, Iraq. His areas of research interests are productivity improvement and design for manufacturing.

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