Improving Cost Estimating Opportunities Within Cutting Table Technology

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Abstract

High accuracy in the estimation of production jobs is necessary for the profitability of print companies. Estimating cutting table technology has proven problematic for industry. For some companies, a process does not exist, while others utilize an existing method that may prove highly inaccurate in establishing reliable estimates. Not only does the lack of reliability impact profitability of the company, but it may also hinder production scheduling. This study seeks to examine cutting times across different tools and substrates to test existing methods and begin to develop a new system for more accurate time standards and cutting table estimation.

This paper presents the results of an initial investigation into predicting cut times and an analysis of existing methods. Results suggest current methods may not be accurate depending on the intricacy or complexity of the design/product being cut. While current methods base estimated cut times and overall job estimates on cut length and complexity, this study highlights that these characteristics may not best meet the needs of the print industry.

Introduction

Profitability is crucial to the survival of any business. For printing companies in the United States, recent data indicates that the average profit margin is under 5% as of 2024 (IBIS World, 2024). Given these tight margins, it's critical to maintain accuracy, consistency, and efficiency in job estimation. One area that frequently presents challenges in estimation includes cutting tables. The difficulty stems from several factors, including variations in the speed of cutting and scoring processes, material being cut (e.g., paperboard, corrugate, wood, metal), the intricacy and shape of the designs. Reliable time standards are essential for successful print production management. With inaccurate job estimates comes unbalanced work schedules. Inaccurate cost estimates will result in underpricing or overpricing a job, holding a heavy importance in the way jobs are estimated.

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In the printing industry, sales tend to function differently than in most other manufacturing processes. We do not produce to sell down the road, meaning we typically do not hold inventory and make it available for purchase. An example of this would be ink manufacturers who produce ink and then sell to their customers when the customer needs it. This process is typically the same for paper manufacturers, plate manufacturers, chemical manufacturers, and most other print supporting industries. This holding of inventory results in an ability to change pricing structure based on the fluctuation of cost in raw materials, thus guaranteeing a profit. In print production, we are asked to essentially bid on jobs for future production. If we price too high, we might be outbid by another company, if we price too low, we may not generate a profit. In fact, we cannot guarantee a profit for our company in any estimate we create as there is no way to predict what challenges may arise as the job moves through the production process.

Most print estimation is based on time standards. As an example, guillotine cutter time is estimated as a function of the type and weight of the substrate, the substrate caliper, the number of lifts needed (as derived by the substrate weight and caliper), and the number of cuts. Knowing these four elements allows for the easy estimation of time needed to complete a job on the guillotine cutter. This estimation process improves the opportunity for profitability, as accuracy in timing each aspect of a job's production (i.e., prepress, press, finishing), leads to better cost estimation and time management.

In gathering estimating process insight from print companies, one common area of confusion is in how estimates are derived for cutting table technology. When asked "How do you estimate jobs on your cutting tables?", several responses have been given, including:

- "We guess!"
- "We are still working on that."
- "It depends on the week."
- "It is loosely based off prior jobs we have completed."

Given this uncertainty in estimating for this technology and the sheer lack of process at all in some regards, we suggest there must be a better way. In fact, a process does currently exist. Expanding on prior research (Wilson & Carey, 2020) and with an emphasis on cutting tools and cutting tables, this research will dive into how the size, shape, and intricacy/complexity of a design plays into the time necessary to complete the cut(s). Through the testing of different designs and substrates, we address the following questions:

1. Can we create more robust time standards that could serve as a proxy for estimating cutting table jobs that are very seldom typical?

2. What categories (e.g., size, complexity, material) might equate to a reasonable and equitable division for easy classification and estimation of cutting table jobs?

Prior Calculations

Earlier research by Wilson & Carey (2020) shares a similar objective to develop a method for estimating cutting time that offers repeatable results. That study created time standards for cutting tables based on three key factors: the material and corresponding cutting tool, the shape of the design, and the size of the item. The method for estimating cutting table production time relied on the following workflow: estimating the circumferences of the object, calculating total circumference (based on number of products needed), calculate cutting time (by way of the speed for the tool to be used), add a complexity factor, account for setup time, and then estimate total time and cost. Figure 1 shows an example of what the existing method looks like.

Cutting Table Production Standards (hourly rate: $115.00)					
Setup time		Cutting tool base rates per linear inch		Shape Complexity	Time increase
single sheet	5 min first sheet; 1 minute per additonal	serigraphy knife	1100 in/min (2794 cm/min)	simple	4x
step & repeat per piece	5 min first sheet + .25 minutes per piece	high frequency knife	900 in/min (2286 cm/min)	medium	8x
milling	10 min first piece; 1 minute per additonal	milliing knife	236 in/min (600 cm/min)	high	12x
kiss cut	add 5 minutes			very high	20x

Figure 1: Example of Time Standards for Cutting Table Production.

To demonstrate how this existing process could present challenges from the start, we will utilize the moderate shape of the Reggie Redbird outline (see Figure 2, Moderate). Here we are solely focused on demonstrating the potential problems with determining the cut distance for a shape outline. In step one, we are asked to estimate the circumference of the object. This is based on one of the following two equations:

a) $C = 2\pi r$
b) $C = \pi d$

Where C is the circumference, π is pi, r is the radius of the shape, and d is the diameter of the shape. In this example, we will utilize equation b. For this shape the diameter is estimated to be 12.36”. To find the circumference then, we multiply the diameter by pi: 12.36” x 3.1415 = 38.83”. Given the existing approach to estimation, we would move on from here to calculate the cutting time as a function of speed and add a complexity factor to the shape (likely medium or 8x).

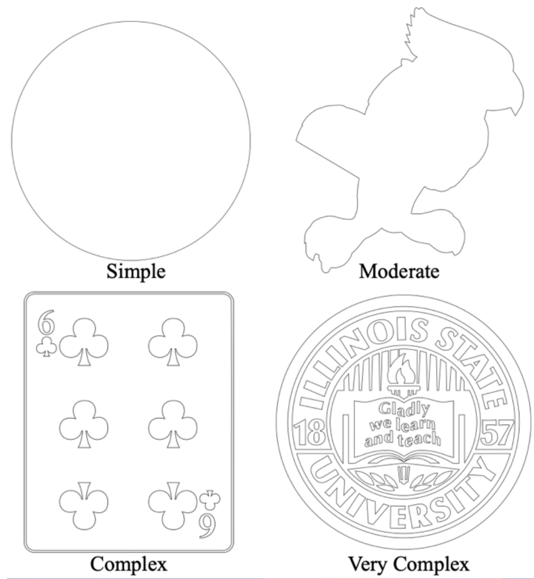

Figure 2: Examples of Shape Complexity.

Given that we created the cut path in Adobe Illustrator, we can utilize the software to determine the actual circumference of the shape, which is 60.25”. This is a significant deviation of 55% from our estimated circumference given existing calculation methods. This demonstrates that estimating the circumference of oddly shaped objects, especially without the artwork file, is hard and often inaccurate.

Based on this prior research and methodology for estimating cutting time, calculating the time required to cut a more complex design such as the ISU seal (see Figure 2, Very Complex), could likely lead to significantly inaccurate predictions. The ISU seal includes not only a circular outline but also a series of intricate internal cuts that greatly impact the overall complexity and duration of the job. With no means to account for the intricacy and amount of cutting within a design/shape outside of the complexity factor multiplier, we move to demonstrate what a cutting time estimate would look like given the existing method of estimation.

- Step 1: Estimate the circumference of the object.
    - Diameter = 13.79”
    - 13.79” x 3.1415” = 43.32”

- Step 2: Total circumference (based on number needed).
  - Assuming one needed, total circumference = 43.32”
- Step 3: Calculate cutting time.
  - Utilizing the High Frequency Knife with a cut speed of 900” per 1 minute: 43.32”/900 = .048 minutes or 2.88 seconds.
- Step 4: Add a complexity factor.
  - Using the highest complexity factor available: 2.88x20 = 57.6 seconds.
- Step 5: Account for setup time.
  - Single sheet = 5 minutes
  - Total time = 5 minutes 57.6 seconds (or 5.96 minutes)
- Step 6: Estimate the cost.
  - Time (in hours) x BHR (base hourly rate)
  - Time = 5.96/60 = .099 hours
  - .099 x $115 = $11.39

Our suspicions are that this estimation falls drastically short of the actual cut time. This approach estimates cutting time based on the circumference of an object, complexity and setup time to generate an estimate. However, we suggest that jobs involving intricate internal cuts may take significantly longer than the time allocated using this original formula. While this work offers a valuable foundation for the print industry, current research builds upon it by examining additional variables such as overall size, cut distances, and advanced complexity factors.

Tools, Software, and Materials

To analyze cutting time variability, ten unique design files were created, each representing varying levels of complexity. The designs were then categorized into one of the four distinct complexity levels. The classification was based on the number of internal and external cuts, curve intricacy, and overall path detail. Each design was processed using the Kongsberg X20 CAD cutting table, within Illinois State University's print center. Two specific knifes were utilized, including the High Frequency Vibracut Knife Tool with the SR6224 blade, known for its speed and versatility, and the Psaligraphy Knife Tool with the SR6150 blade, which is suited for more delicate and detailed cutting operations. Both knives were first tested at the default speeds with high frequency 16.4 in/sec and psaligraphy at 19.7 in/sec.

Testing was conducted on two widely used substrates to account for material variability: paperboard with a material thickness of 0.024 inches and corrugated board measuring 0.063 inches in thickness. To further evaluate the influence of design scale on cutting time, each of the ten designs was produced in three different sizes by applying scalable factors of 50%, 100%, and 150%. This allowed for an assessment of how increasing surface area and design proportions affect overall production time. Additionally, each design incorporated a minimum of three distinct cutting paths, ensuring a baseline level of complexity and interaction with both tools and materials. The data collected from these tests serve as a basis for assessing existing time estimation models.

Research Approach

Examples of how shapes were classified can be found in Figure 2. A simple shape was inclusive of typical/standard shapes (e.g., circle or rectangle). A moderate shape was inclusive of shapes where circumference could not easily be determined by simply knowing the radius or diameter of the bounding box (i.e., Reggie Redbird outline). A complex shape began to incorporate internal cuts, not just circumference of the shape (i.e., club card). A very complex shape incorporated significant detail and complexity, potentially in both the circumference and internal cuts (i.e., University seal).

To give context to the process, Adobe Illustrator was used to determine the official cut dimensions for each shape, including circumference of the shape for simple and moderate classified shapes, and circumference and internal dimensions for complex and very complex classified shapes. These dimensions were assessed for each of the three shape sizes of 50%, 100% (fit within a 14” x 14” square), and 150%. Cut dimensions can be found in Table 1.

Shape	Complexity	50%	100%	150%
1	Simple	21.91”	43.84”	65.73”
2	Simple	22.67”	45.34”	68.01”
3	Simple	36.75”	73.5”	110.25”
4	Moderate	40.725”	81.45”	122.175”
5	Moderate	30.125”	60.25”	90.375”
6	Moderate	24.98”	45.34”	74.94”
7	Complex	83.715”	167.43”	251.145”
8	Complex	56.225”	112.45”	168.675”
9	Very Complex	240.145”	480.29”	720.435”
10	Very Complex	181.685”	363.37”	545.055”

Table 1: Shape Size and Classification Characteristics

Results

Table 2 shows the average cut times on corrugate using the high frequency knife for each of the shapes in the three different sizes. What is important to note and observe is that despite the differences in cut lengths, the time to cut does not increase at the same level. For example, for shape four the cut length at 50% was 40.725”, and the cut time with the high frequency knife on corrugate was one minute and nine seconds. Despite the cut distance tripling (from 40.725” at 50% to 122.175” at 150%), the time to cut only increases by 13 seconds.

While the data in Table 2 are specific for the high frequency knife on corrugate, the shapes were also cut using the same knife on the paperboard substrate. Despite the difference in substrate thickness, the difference in cut times were minimal across all shapes and sizes, ranging from the most similar cut time (i.e. closest) at 1 second (several shapes) to 11 seconds at the largest difference (shape nine at 100%).

Shape	Complexity	50%	100%	150%
1	Simple	19 sec	23 sec	26 sec
2	Simple	21 sec	24 sec	28 sec
3	Simple	39 sec	46 sec	54 sec
4	Moderate	1min 09 sec	1min 19 sec	1min 22 sec
5	Moderate	1min 11 sec	1min 27 sec	1min 40 sec
6	Moderate	48 sec	52 sec	52 sec
7	Complex	1 min 47 sec	2min 7 sec	2 min 57 sec
8	Complex	38 sec	46 sec	42 sec
9	Very Complex	9 min 20 sec	9 min 51 sec	11 min 30 sec
10	Very Complex	7 min 13 sec	7 min 17 sec	8 min 4 sec

Table 2: Cut Times with HF Knife on Corrugate at 16.4in/sec.

Shape	Complexity	50%	100%	150%
1	Simple	21 sec	24 sec	26 sec
2	Simple	21 sec	25 sec	28 sec
3	Simple	39 sec	48 sec	55 sec
4	Moderate	1min 02 sec	1min 17 sec	1min 22 sec
5	Moderate	1min 10 sec	1min 27 sec	1min 33 sec
6	Moderate	44 sec	54 sec	52 sec
7	Complex	1 min 37 sec	2min 11 sec	2 min 57 sec
8	Complex	38 sec	49 sec	42 sec
9	Very Complex	7 min 38 sec	9 min 58 sec	13 min 34 sec
10	Very Complex	6 min 41 sec*	7 min 27 sec	8 min 42 sec

Table 3: Cut Times with Psaligraphy Knife on Paperboard at 19.7 in/sec.

Table 3 shows the average cut times on paperboard using the psaligraphy knife for each of the shapes in the three different sizes. Similarly to the results with the high frequency knife, it is important to note and observe that despite the cut length differences, the cut time does not increase proportionally. Using the same example, for shape four the cut length at 50% was 40.725”, and the cut time with the psaligraphy knife on paperboard was one minute and two seconds. Despite the cut distance tripling (from 40.725” at 50% to 122.175” at 150%), the time to cut only increases by 20 seconds.

While the data in Table 3 are specific for the psaligraphy knife on paperboard, the shapes were also cut using the same knife on the corrugate substrate. Despite the difference in substrate thickness, the difference in cut times were minimal across all shapes and sizes, ranging from the most similar cut time (i.e. closest) at 1 second (multiple shapes) to 5.4 seconds at the largest difference (shape nine at 50%).

When it came to the psaligraphy knife, the standard speed was 19.7 inches per second. In Table 3, the time for shape 10 at the 50% level is highlighted as this is not a comparable value. Due to the detail in and size of the design, this shape could not be cut at the established settings. At approximately 2 minutes and 20 seconds into the cut, the knife would start to hook on the design and pull apart the material requiring a stoppage of the machine (see Figure 3).

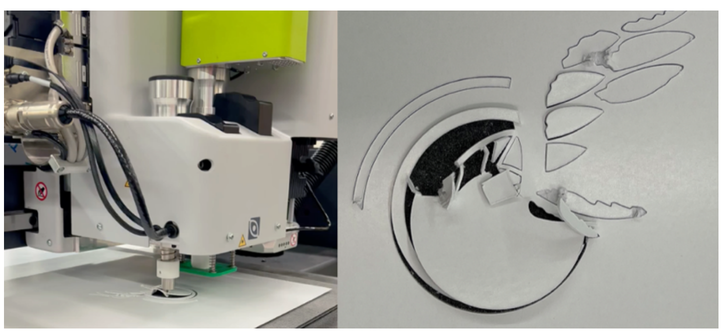

Figure 3: Example of Shape 10 Problem Cut.

To address the issue, the psaligraphy knife speed was slowed down to 16.4 inches per second to match the speed of the high frequency knife. This resulted in a clean cut with no further issues, however due to the change in speed, it cannot be used to make direct comparisons with the other shapes or sizes. There were no other issues cutting the shapes at any size for the high frequency knife or the psaligraphy knife.

Another important observation that should be made between cutting tools and the cut speeds, is that there are instances where the shape at 150% cuts in either the same time or faster than the same shape at 100% (e.g., shapes 6 and 8 for both knives). This could be due to the intricacies of the designs and how expanding the size of the paths allows for a smoother stop/start transition on the machine.

However, with that noted, there were no instances across tool and substrate combinations where the 100% size cut more quickly than the 50% size.

Table 4 shows the side-by-side comparison of each shape at the 100% level on both substrates when cut with the high frequency knife. Note how similar the times are, with the largest difference being 11 seconds for shape nine. Another thing that is intriguing about this comparison, is that there is not one substrate that continuously cuts quicker, as shapes 4, 5, and 9 cut faster on paperboard than corrugate.

Shape	**Complexity**	**Corrugate - 100%**	**Paperboard -100%**
1	Simple	23 sec	28 sec
2	Simple	24 sec	25 sec
3	Simple	46 sec	49 sec
4	Moderate	1min 19 sec	1min 15 sec
5	Moderate	1min 27 sec	1min 26 sec
6	Moderate	52 sec	55 sec
7	Complex	2min 7 sec	2 min 9 sec
8	Complex	46 sec	48 sec
9	Very Complex	9 min 51 sec	9 min 40 sec
10	Very Complex	7 min 17 sec	7 min 20 sec

Table 4: Side-by-Side Comparison of High Frequency Knife on Different Substrates.

Tables 5-7 present the side-by-side comparisons between the cut times with different knives on different materials (HF on corrugate and psaligraphy on paperboard). These comparisons are done this way to show how similarly the cut times are across tools and materials.

Shape	**Complexity**	**HF - 100%**	**Psaligraphy -100%**
1	Simple	23 sec	24 sec
2	Simple	24 sec	25 sec
3	Simple	46 sec	48 sec
4	Moderate	1 min 19 sec	1 min 17 sec
5	Moderate	1 min 27 sec	1 min 27 sec
6	Moderate	52 sec	54 sec
7	Complex	2 min 7 sec	2 min 11 sec
8	Complex	46 sec	49 sec
9	Very Complex	9 min 51 sec	9 min 58 sec
10	Very Complex	7 min 17 sec	7 min 27 sec

Table 5: Side-by-Side Comparison at 100%.

Shape	Complexity	HF - 50%	Psaligraphy - 50%
1	Simple	19 sec	24 sec
2	Simple	21 sec	25 sec
3	Simple	39 sec	48 sec
4	Moderate	1 min 09 sec	1 min 17 sec
5	Moderate	1 min 11 sec	1 min 27 sec
6	Moderate	48 sec	54 sec
7	Complex	1 min 47 sec	1 min 37 sec
8	Complex	38 sec	38 sec
9	Very Complex	9 min 20 sec	7 min 38 sec
10	Very Complex	7 min 13 sec	6 min 41 sec*

Table 6: Side-by-Side Comparison at 50%.

Shape	Complexity	HF - 150%	Psaligraphy - 150%
1	Simple	26 sec	26 sec
2	Simple	28 sec	28 sec
3	Simple	54 sec	55 sec
4	Moderate	1 min 22 sec	1 min 22 sec
5	Moderate	1 min 40 sec	1 min 33 sec
6	Moderate	52 sec	52 sec
7	Complex	2 min 57 sec	2 min 57 sec
8	Complex	42 sec	42 sec
9	Very Complex	11 min 30 sec	13 min 34 sec
10	Very Complex	8 min 4 sec	8 min 42 sec

Table 7: Side-by-Side Comparison at 150%.

One of the most interesting observations to come out of these comparisons is the transition in time between tools. We will return to a familiar example, the ISU seal (Figure 2 – Very Complex). At the 100% size, there is a 7 second difference in cut time between tools and substrates, with the high frequency knife cutting slightly faster. At the 50% size, there is an astounding 1 minute and 42 second difference, where the psaligraphy knife cuts more quickly than the high frequency knife. At the 150% size, the high frequency knife again cuts quicker, by 2 minutes and 4 seconds. It is important to note that it is only within the very complex shapes that we see such significant differences in cut times. In all other cases, differences between tools and substrates equates to 16 seconds or less.

Finally, we do want to make a note about cutability. As mentioned previously, outside of the cutting issue with shape 10 at 50% using the psaligraphy knife on paperboard, no other shapes experience *cutting* issues, meaning all cuts were able to be completed. This does not mean however that shapes should be cut, or that they would be functional products when complete. As Figure 4 depicts, while shape 10 was successfully cut on corrugate at the 50% size, the pieces fell apart and were not functional when removed from the cutting table. This was also true when it came to the paperboard cuts, as the tools were unable to make such precise cuts without proceeding into other aspects of the shape as the knives turned.

Figure 4: Cutability Example.

Discussion

These results highlight that the size and cut distance for each shape along with a built-in complexity factor as prior research has done, do not necessarily work to accurately aid in building an estimate for cutting table technology. Despite instances where the distance to cut has tripled, the cut time does not reflect this change in most cases. Additionally, the complexity factors previously established do not compensate for the intricacies of many designs.

In observing the cutting process, as the tools work to cut each design, they must stop, lift, and turn each time an angle or direction change in encountered. Depending on the intricacy of the design and number of angles or direction changes necessary, we see that each machine stop adds to the overall total time. It is possible then, that attempting to determine the number of times the machine would have to pause, lift, and turn the knife prior to resuming the cut could help in improving estimation. This may in fact be a better means of estimating time when paired with cut distance than simply looking at cut distance and shape complexity alone. In fact, the number of stoppages for knife direction changes could replace the complexity factor itself.

We will return now to the quote from the introduction of this paper, where we utilized the existing time standards and process to estimate a job for one of our very complex shapes (see Figure 2 – Very Complex). Recalling the estimate, we saw that the expected cut time with a complexity factor of 20 was 57.6 seconds. With the 5-minute setup time, that brought the estimated charge for the cut to $11.39. We can see from Table 2, that the actual cut time for this shape with the high frequency knife on corrugate was 9 minutes and 51 seconds. This reflects a significant deviation from the predicted cut time. Utilize the actual cut time and the setup time, we arrive at a total time of 14.85 minutes or .2475 hours. This changes the total cost for the cut to $28.46, a difference of $17.07.

While that difference in cost may seem insignificant to some, over time and with repeated job estimate inaccuracies, that cost adds up. In an industry where the average profit margin is below 5% (IBIS World, 2024), we believe any opportunity for more accurate job estimation is worth pursuing.

Conclusion

The results of this study suggest that we have been approaching the estimation of cutting table technologies from a faulty perspective. Clearly, the size or length of the cut to be made is not the most important factor in determining how long a design/product will take to complete. While intricacy/complexity of the design does matter, to what extend seems highly variable as well.

While this study has shed light on some challenges when it comes to estimating for cutting table technologies, and has highlighted the problems with existing methods, we are stopped far short of a good process or estimation method to improve on what exists. More research is necessary to determine what characteristics of a product/design are going to give us the best opportunity to accurately gauge cut times. Perhaps there is a means by which we could utilize the number of angles within the design, thus number of transitions where the knives must stop, lift, and turn, to more accurately assess time to complete the cut. There is a possibility that with the use of artificial intelligence (AI), a model can be developed where an approximate number of angles and cut distance can be used along with a specific value for angle transition time (i.e., adding a fraction of a second for each time the tool needs to stop, lift, and turn) to more accurately predict cut time than utilizing a complexity factor.

Further research is also needed to expand on the tools and substrates used to determine if there are some cutting processes where in size and cut length do play a significant role in determining cut time.

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