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MAE 364 Manufacturing Processes

Comparative Analysis Project
Gate 4 - Final Report

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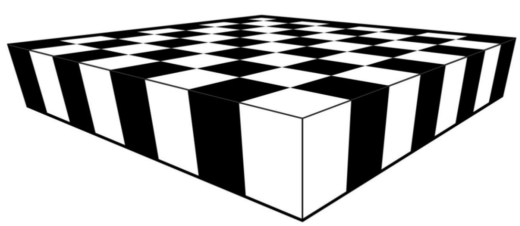

INTRODUCTION

Our team aims to manufacture a hat themed chess set for use in the New York City municipal building. To this point, we have completed three gate steps towards the final product. In the first, we specified our theme and outlined potential manufacturing processes for our chess pieces. Next, we brainstormed ideas for specific hat themed chess pieces by creating sketches of six full sets of chess pieces. In our last gate, we performed analysis on the designs to reach a final decision on the chess piece we would manufacture.

In this paper, we aim to outline the benefits and disadvantages of alternative manufacturing methods. Our chosen method is STL printing, an additive manufacturing method useful for rapid prototyping. We will explore the differences between our chosen method and traditional manufacturing methods. Chess piece concepts developed from Gate 2 will be referenced when necessary to show where certain methods are particularly beneficial or disadvantageous. These designs can be found in the appendix for easy reference. We hope to come to a conclusion in favor of our chosen manufacturing method. A picture of our printed chess piece can be seen below.

Figure 1: Printed Chess Piece

ALTERNATIVE MANUFACTURING METHODS

Turning

An alternative manufacturing that could be used to produce our chess set is turning. This involves rotating the material and having a cutting tool to remove the material in a radial fashion. This method can be used for various types of materials like wood and metal. This type of manufacturing is completed on a lathe, and there are various different types of turning that can be performed, depending on the desired final shape. This method has its advantages and disadvantages that will be discussed.

This method has a couple of drawbacks associated with it. The first being that the final geometry of the product must be radially symmetric. Since this method involves rotating the work part about an axis, there is no option for having unsymmetric parts. Another negative is that most defects in this process are either in the form of inaccurate surface dimensions or surface roughness. Chess pieces have to have good relative dimensions with each other and if this method does not offer a great tolerance then it would not be suitable for our needs. Also, this method produces a significant amount of tool wear which will be costly in the long run if our chess set were to be mass-produced.

There are advantages to using turning as well. The first is that this method does produce a good surface finish. This is important so that the chess pieces will look appealing to the people playing with them. Unlike other manufacturing methods, turning requires a less amount of energy. By consuming less energy, the cost associated with manufacturing will be reduced. The chips that are formed from cutting are also generally easier to collect after a cutting operation has concluded. The process is also quite simple, as the basic parameters are the speed, feed, and depth of the cutting tool.

When considering the six designs presented in the second gate, there are only two designs that could work with this method. These designs are symmetrical, so it would be perfect for this kind of cutting operation. They are Vladimir’s and Ayesha’s chess pieces that work. However, if we altered James’ design just a little from the second gate, just like what was done in gate three for printing, turning could also be used with this manufacturing design. The rest of the designs have too complex of a geometry that would not be achievable using this manufacturing method.

Milling

Another alternative manufacturing could be milling. This method utilizes a multiple edge cutting tool that rotates to remove the material from the work part that is usually fed past it. This process can utilize computer numerical control (CNC) in order to automate the cutting process to reduce human error. This method can be completed on a machining center, which can have up to five-axis degrees of freedom and can also perform drilling, However, drilling is not that useful in our situation and we are more concerned about the milling aspect. Milling can be performed on a wide variety of materials including wood, metal, and wax. As expected, this manufacturing method has its advantages and disadvantages.

One disadvantage of this operation is that it is not good at making radial cuts. This means that if a piece has radial symmetry that mailing would not be a good choice as a manufacturing method. A more suited geometry would be more of a flat plate of some sort. Another drawback is that the machining centers are usually very expensive and would have a large upfront cost associated with it. The energy required for this operation is also quite large and would also increase the cost of production.

There are also many advantages to using this manufacturing method. One advantage is that this method is very precise and has very small tolerances. This high precision is due to the machining center and the CNC, if done by hand the tolerance would be larger. Once the machine is programmed it will be able to make a part over and over with the exact same geometry. This will make chess sets that have the same looking chess pieces, which is important to the users. The machines are also very fast at milling and therefore a large number of pieces can be produced in a small amount of time.

Since our chess set theme is hats, all of the hats have a rounded feature to them. Therefore this method would not be very efficient in manufacturing this product since it is not good with radial cutting. However, if we were to look at just the body parts of the designs presented in gate two, we could see which designs would be good candidates for this method. After examining the designs, there is really only one design that could benefit from this operation and it is Damian’s queen design. With this design, there is a bust of a person that is meant to be flat, which is perfect for milling. The flat brim of the hat also plays perfectly into the milling advantages.

Injection Molding

Another manufacturing method to consider is injection molding. With this method, plastic or metal is injected into a shaped cavity through a nozzle and left to harden. The cavity plates are then opened and the finished part is then expelled out by the use of ejector pins. This requires the design and creation of a mold for the liquid plastic or metal to be inserted within. This only has to be done once for each geometry that is desired. This method does have its advantages and disadvantages.

One disadvantage is that the creation of the mold required for this process can be expensive to manufacture at the beginning of the manufacturing. Along with the cost, the time it takes to make a mold is also high and will set back the production. Another problem with this method is that if the design of a chess piece was needed, then a whole new mold would have to be manufactured. This will then have the same problems of cost and lead time as the mold of the first design had. Also, certain geometries cannot be created with this process. Once the mold is opened for the piece to be ejected, there cannot be any curved features that will prohibit this motion.

There are also a variety of advantages associated with injection molding. One is that this method can produce a large number of products very quickly. This would make it ideal for mass production. This method is also very affordable once the mold is created and the production cost after that is very low. Also, the amount of wasted material for every cycle is minimal. This is because the material is injected into the mold until full, and then left to harden. No cutting operation to remove material is used for this method. This will save money from not wasting the material during production like other manufacturing processes. Lastly, this method allows for an easily repeatable product so that each piece will come out the same.

When looking at the six designs from gate two, every design would be able to work with this method. Each design has a simple enough geometry so that it will be able to be ejected at the end of the process. Some designs look like it could pose a problem in this regard, but simply reorienting that piece would allow us to overcome this issue. The pieces are also relatively small, so a large mold would not be required that would also help reduce cost and lead time associated with this method.

Lost Wax Casting

Another alternative manufacturing method could be the lost wax casting process. This method involves the creation of a wax pattern connected to a central sprue that is then coated in a layer of refractory material. This is then heated up so that the wax melts and the liquid wax can be poured out of the mold. Then, the mold is filled with the molten metal and left to solidify. The refractory material is broken off and the parts are recovered. This method has some advantages and disadvantages.

One disadvantage is that this method requires a large number of steps in order to get the final product. This is due to the need for a pattern to make a mold and then to melt the pattern away. Having a large number of steps will reduce production time overall. Another downside of this method is that it is relatively expensive with regards to other methods that will accomplish the same task. Another negative is that casting pieces with a core is relatively difficult to accomplish.

There are also a good amount of advantages when it comes to lost wax casting. One advantage is that parts with a large amount of complexity can be cast. This process also doesn't have a huge restriction on the type of metal that can be used, almost any metal can be used. This process is also a net shape process, meaning that additional machining after this process is not usually required. This means that the surface finish is very good with this method. Having a process that is already capable of having a good surface finish after the creation of the part is extremely desirable as it will save money from needing more steps. Lastly, the wax can be collected to make a new set of patterns for the next cycle. This will also save on money as new wax wouldn't be required each time.

Since lost wax casting is able to cast parts with complex geometries, every design of our pieces from gate two can be made with this method. There is also not a single design that requires a core, so the difficulty is casting that feature does not need to be worried about. Also, because each piece is also of a small geometry, the number of patterns that could fit on a sprue would be fairly large. This would mean a large batch can be made at once and help mitigate the fact that the time required for this method is fairly lengthy.

CASES TO CONSIDER

Mass Production

In the case of Mass Production, the optimal conditions include repeatable, consistent processes with low lead-time and a low cost of production. Consistency of properties, low chance of defects, and low cost of production are of critical importance.

Table 1. Importance of Criteria in the case of Mass Production.

	Cost	Lead Time	Production Volume	Accuracy	Waste	Modularity
Importance	3	3	3	2	3	1

Injection molding, milling, and turning - all of these processes would be a great choice in the case of Mass Production. All these processes would have good production outputs in case of mass production. However, the injection molding casting process would be preferable to others considering the criteria of mass production. Reusability of the mold and a complete geometry preventing the need for additional milling both contribute to less cost and lead time. Also, the process would provide good surface finish and have the advantage of large batch production. After the overall considerations, the lost injection molding process appears to be the best choice of manufacturing process than other processes under consideration.

The injection molding process can create all of our designs with minimal issue, so long as the proper mold is created. However, more complex designs, such as those in Ashraf's or Wenzhi's proposals would be less desirable in this case due the increased difficulty in creation of the mold and potential issues with ejection of the pieces from the mold. These issues are not insurmountable, but make other options more viable for mass production. In general, simpler designs are easier, and less costly, to produce, which are the guiding criteria for mass production.

Prototyping

In the case of prototyping, the optimal conditions include processes with low lead-time which can be used to create parts with modifications. Cost is not quite as necessary in this case but is still preferable to be lowered.

Table 2. Importance of Criteria in the case of Prototyping.

	Cost	Lead Time	Production Volume	Accuracy	Waste	Modularity
Importance	2	3	1	2	1	3

When considering prototyping, both milling and turning seem to be good alternative choices for additive manufacturing. However, milling would be preferred due to high precision outcome and fast lead time as these two criteria benefit the case of prototyping. A faster process helps prototyping in greater context since it creates room for further revisions in a short period of time for the best final outcome. Notably, both turning and milling are constrained by their difficulty in creating certain part geometries, making them not viable for use in creating some designs, and so other processes, such as lost wax casting, must be used in those instances.

In light of this use of milling, the designs proposed by Vladimir and Damian are likely to be the most viable. Milling is constrained by its difficulty in creating radial surfaces, so the designs of Vladmir and Damian, which often include flat surfaces, are optimal. If turning is an option, then several of the designs of James and Ayesha are viable, as they have radial symmetry, which is the main constraint of turning.

Low-Quantity, High-Quality

In this case, the optimal conditions include consistency in the lack of defects and accuracy of part properties. Parts manufactured must be precise, not just accurate. Cost, while important, is less critical in this case.

Table 3. Importance of Criteria in the case of High-Quality Manufacturing.

	Cost	Lead Time	Production Volume	Accuracy	Waste	Modularity
Importance	2	1	1	3	1	1

As the accuracy of the process and absence of defects are priorities, milling and injection molding both would work great as alternative processes. Both processes produce good surface finish with high dimensional accuracy. With milling, cost is much cheaper than creating a new mold for our design. This comes with a tradeoff in accuracy, considering the radial surfaces of our designs.

Injection molding surpasses milling in cost, but allows for maximum geometrical accuracy. In particular, this would be a viable way to produce the designs proposed by Ashraf and Wenzhi, as both sets of designs are fairly complex. Regardless, all others are viable as well, and the less complex designs do cut down lead time somewhat, however that is not a great concern in this particular case.

<u>Unique or Personalized Part Production</u>

In this case, the optimal conditions include the ability to modify the part geometry or properties for each individual instance of the part. Low cost and lead-time are preferred but not necessarily critical to this case.

Table 4. Importance of Criteria in the case of Unique Part Production.

	Cost	Lead Time	Production Volume	Accuracy	Waste	Modularity
Importance	2	1	1	3	2	3

Lost wax casting appears to be the most promising alternative to the additive manufacturing process. Modularity, in this case the ability to change the specifications of each part produced, is the most important criteria for this case. As such, injection molding is not viable, as it reuses the mold for every part. Turning and milling can be used for this, however they have geometric limitations which may interfere with this case. As such, the optimal choice is lost wax casting, as it handles complex parts without issue, and it has a new mold for every casting, such that the mold can be changed each time.

With this freedom of complexity, once again all designs proposed can be used. It is more cost effective to use simpler designs, as the creation of the mold is the longest influence on lead time, however, since lost wax casting is a net shape process, the complex designs are viable as well. Due to the definition of the case, slight modifications are necessary to the design for each part produced, so it may not be as wise to use these complex designs, which may not work as well when altered. As such, the parts made by James and Vladimir are notably viable, as they are general enough to be modified without issues arising in design.

Table 5. Rankings of Traditional Manufacturing Cases by Manufacturing Case.

	Turning	Milling	Injection Molding	Lost Wax Casting
Mass Production	2	3	1	4
Prototyping	3	1	4	2
Low Quantity, High Quality	4	2	1	3
Unique Part Production	3	2	4	1

REQUIRED DESIGN CHANGES

Turning

Firstly, all the parts created by a turning operation must be axisymmetric, because this method relies on the part rotation. Many of the designs we created are not axisymmetric, and the geometry of these designs has to be changed, or other alternatives will be required. Thus, the complicated shapes attached to the main body of the parts will be removed. For some designs, eliminating the complex non-axisymmetric shape will also eliminate the context they originally expressed. Painting or other methods might be used for the axisymmetric parts to represent the same meaning and idea. The tolerance can be very small due to the great precision of turning operations. The materials are limited to wood or metal due to the method, and wood will be preferred for the chess piece design.

Milling

The milling process can make the geometry of the parts more complex. Hence, many of the more complex designs and geometries can be maintained. Despite its usefulness in creating certain parts with high accuracy, milling is not ideal for radial surfaces. The circular cross section of some parts would pose challenges in the process. Thus, the main body of those parts should be adjusted to a rectangular shape. With geometry adjustments, the surface finish quality of milling is very high. This allows for lower tolerance of parts. The material used will be wood or metal. Wood is more favorable as it is more commonly used in traditional chess sets.

Injection Molding

Injection molding is a great method to achieve the designed pieces. Redesign of the parts' geometries is not necessary if injection molding is used. High tolerances can also be achieved using injection molding. Injection molding can handle the most complex geometries in our designs. The parts are also small, which is ideal for this method, as large parts can not be created using injection molding. Waste of material and labor is also minimized using injection molding. However, this method has restrictions on materials. For example, if wood or metal is chosen as the material, injection molding can not be used. Injection molding is mostly suitable for use with plastic materials. Also, the cost of machinery and dies will be expensive.

Lost Wax Casting

Lost wax casting is another great method to achieve the designed parts. Redesign of the parts is also not necessary if the lost wax casting is used. However, since this method involves very skilled labor, redesigning the parts to make the intricate details simpler will save time and money. The shape needs to be carved using wax first. 3D printing the wax figures can also save time, effort, and labor. This method can achieve high tolerances but the surface finish will not be as good as the other three methods. Finishing and polishing will be required to get to the final product. The wax that is used to create the shape can be reused but the wax may be of the additional cost.

APPENDIX: ALTERNATIVE CHESS DESIGNS

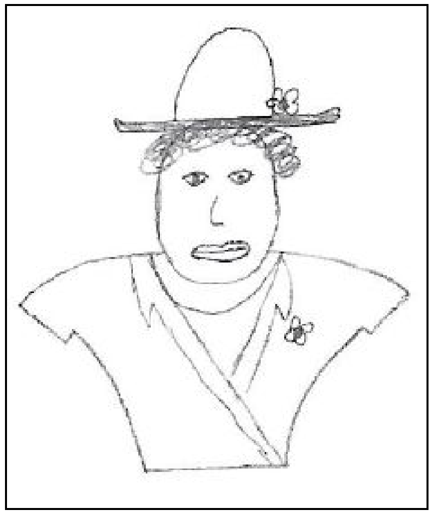

Figure 2: Damian's Queen

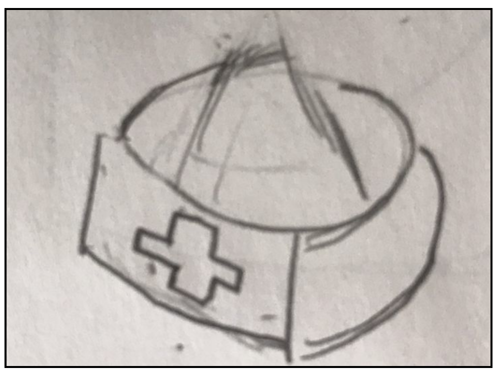

Figure 3: Vladimir's Queen

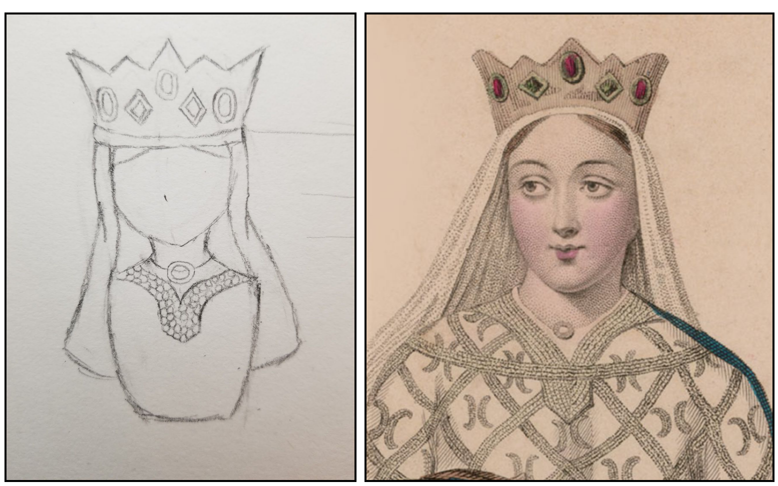

Figure 4: Ashraf's Queen

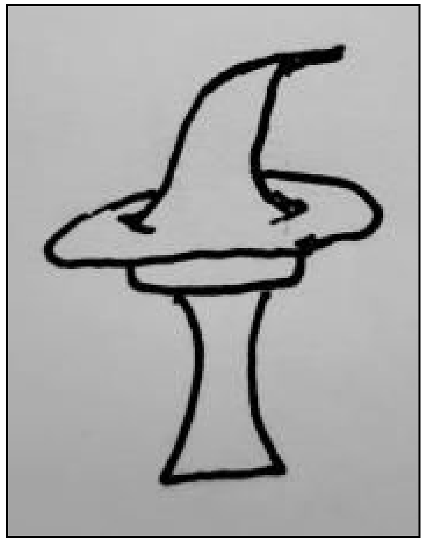

Figure 5: James' Queen

Figure 6: Wenzhi's Queen [7]

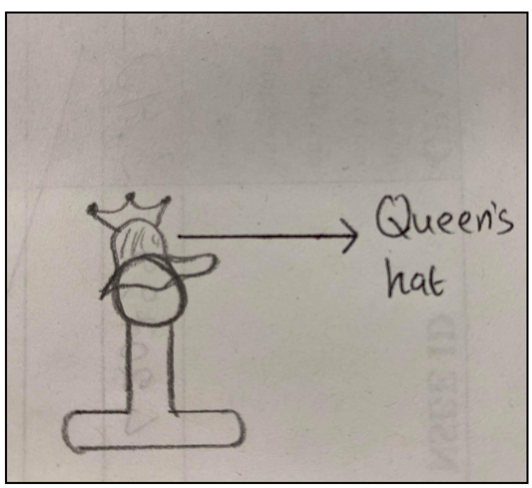

Figure 7: Ayesha's' Queen