# Manufacturing Insoles with HP Multi Jet Fusion Technology


## SUMMARY

The purpose of this document is to present the most important insights regarding insole applications and why HP Multi Jet Fusion (MJF) technology will disrupt the way insoles are made.

HP MJF technology allows manufacturers to produce a **higher quality product in a much more repeatable** way than with vacuum forming or machining. Current costs for such products range from $7 to $35 per pair. In most cases this does not take into account the end-to-end (E2E) cost (i.e., labor costs, space, machining that has already been amortized). The average cost per pair when manufacturing insoles with HP MJF technology is approximately $14 to $22 per pair, depending on how fixed costs are considered. The **target customer for HP Jet Fusion 3D Printing Solutions** (HP Jet Fusion 3D 4210/4200 Printing Solutions) is one with a demand of **at least 7,000 pairs per year.** Optimal production costs will be achieved when the customer produces up to 20,000 pairs per year, per HP Jet Fusion 3D Printing Solution.

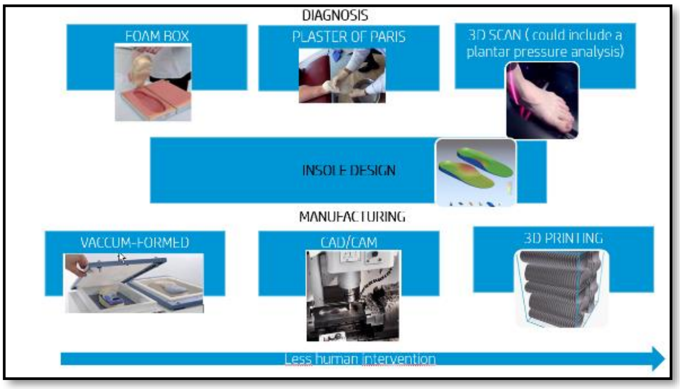
## INSOLES OVERVIEW

Foot insoles are mechanical devices that attach to the shoe or are placed inside the shoe to assist in maintaining or restoring normal alignment and the natural function of the foot. Custom orthotic foot insoles are prescribed by an orthotist, podiatrist, or any other healthcare professional with a background in biomechanics.

From the many existing insoles on the market, the insole produced with HP MJF technology is printed using HP 3D HR PA 11, resulting in the rigid foundation of the hard insoles, which is called a three-quarter–hard reinforcement. This part will be glued to a soft cushioning.


• **Prefabricated insoles** provide general arch support or cushioning to areas of the foot that don't require specific personalized features and are the cheapest to purchase. These are mass-produced using molds and can be bought off the shelf. The selling price is approximately **$8 to $100.** Because of cost, insoles produced with HP MJF will be able to compete **only in the premium market for low- to mid-series volumes with small or medium foot sizes** (i.e., children and women).

• To create **custom-made insoles**, an orthotic is manufactured following a diagnosis of the patient's foot. These types of insoles often provide the best fit and offer the best results as they are customized to the user. They also are the perfect fit for HP MJF technology. The price when sold at a store or through a clinician can vary from $**150 to $800**.




Insoles are classified as either hard insoles or soft insoles. Hard insoles are usually machined or vacuumed in polypropylene (PP). Soft insoles are mainly made of machined EVA. Soft insoles are easier and less expensive to machine. Nevertheless, hard insoles are perceived as a higher-value product, and some customers that used to produce EVA insoles are switching to those produced with HP 3D HR PA 11.

A multi-step process is required when creating customized orthotics, which can be divided into three steps: **diagnosis, insole design, and manufacturing**. There are three options for the **diagnosis** stage:

**Tablet scanners** are very portable and scalable with a cost investment of less than $1,000. An app assists in completing the diagnosis form, and then a precision scan of approximately +/- 0.2 mm is taken.

**Fixed camera/laser stations:** Several options exist for this solution with up to two cameras, five cameras, lasers, and/or pressure sensors. This solution is more expensive (e.g., $3,000 to $10,000 per system) but it is easier to use for customers such as children.

**Dynamic analysis:** Some specialized centers for high-performance sports use cameras, pressure sensors, and dynamic sensors to analyze the way patients walk/run. This solution implies a higher investment compared with the two previous ones.

The **design process** must be conducted with a specific design software that adjusts a design to a patient's diagnosis. Available software can process a design in 1 to 20 minutes and is a key part of success for customers who use HP MJF technology. Manufacturing can be analogical with vacuum forming, digital with CNC, or digital with HP MJF.

## TARGETING CUTOMERS

Customers who can produce insoles with HP MJF technology and HP Jet Fusion 3D 4210/4200 Printing Solutions should fulfill the following criteria:

- ✓ Current or target production of at least 7,000 pairs per year. Optimal cost at 20,000 pairs per year.
- ✓ Have a product where the total cost of $12 to $30 per pair is acceptable for the business, with important savings in labor and space.
- ✓ Make custom-made insoles or generic high-premium athletic insoles.
- ✓ Have a digitalized query process for diagnosing and scanning.
- ✓ Have design software to quickly adjust the design, or willing to use an existing solution.
- ✓ Are willing to innovate and put higher premium products into the market.

For lower volume and delocalized productions, HP Jet Fusion 500/300 Series 3D Printers also could be suitable, but currently it is only possible to use in HP 3D HR PA 12 material with these printers, and further business cases must be analyzed.

## WHY HP MJF

### Functional improvement with Additive Manufacturing

Cost will not be the main incentive for a manufacturer with an established and optimized process to switch to 3D printing. But Additive Manufacturing is disruptive in this industry, and HP MJF is the best technology available today with the best productivity[1] and cost per part.[2]

3D printing with HP MJF allows manufacturers to:

- Improve **comfort by reducing weight and thickness** where material is not needed (free holes and a minimum thickness of 1 mm).
- Improve rigidity only where needed with **local reinforcements.**
- Improve **grip** between insole and shoe by applying textures.
- Add serial numbers, names, and brand **marking for free** (avoiding stickers during the manufacturing process).

### HP 3D HR PA 11 is the perfect material

**HP 3D HR PA 11 is the right material for this application** thanks to its high elongation at break[3] and its perfect fit in terms of biomechanics, as explained in the performance chapter. Printing with **HP 3D HR PA 11 in Balance** mode will ensure the best insole integrity for abusive uses or tests; HP 3D HR PA 11 in Fast mode has been evaluated and provides a more competitive cost although it slightly increases the variability in geometry tolerances. Strength elongation is a property that is required for flexural and fatigue flexural reasons with an appropriate rigidity. HP 3D HR PA 12 in Balanced mode is in use in this process, but it is a more brittle material

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[1] Based on internal testing and simulation, HP Jet Fusion 3D average printing time is up to 10 times faster than average printing time of comparable fused deposition modeling (FDM) and selective laser sintering (SLS) printer solutions from $100,000 USD to $300,000 USD on market as of April 2016. Testing variables for the HP Jet Fusion 4210/4200 Printing Solutions: Part quantity: 1 full build chamber of parts from HP Jet Fusion 3D at 20% of packing density versus same number of parts on above-mentioned competitive devices; Part size: 30 $cm^3$; Layer thickness: 0.08 mm/0.003 inches.

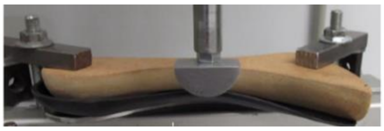
[2] Based on internal testing and public data for solutions on market as of April 2016. Cost analysis based on: standard solution configuration price, supplies price, and maintenance costs recommended by manufacturer. Common cost criteria: using HP 3D High Reusability PA 12 material, and the powder reusability ratio recommended by manufacturer. HP Jet Fusion 3D 4200 Printing Solution average printing cost per part is half the average cost of comparable fused deposition modeling (FDM) and selective laser sintering (SLS) printer solutions from $100,000 to $300,000 USD. Cost criteria: printing 1 build chamber per day/5 days per week over 1 year of 30 $cm^3$ parts at 10% packing density. HP Jet Fusion 3D 4210 Printing Solution average printing cost per part is 65% lower versus the average cost of comparable FDM and SLS printer solutions from $100,000 to $300,000 USD and is 50% lower versus the average cost of comparable SLS printer solutions for $300,000 to $450,000 USD. Cost criteria: printing 1.4 full build chambers of parts per day/5 days per week over 1 year of 30 $cm^3$ parts at 10% packing density on fast print mode.

[3] Tested with diluted alkalies, concentrated alkalies, chlorine salts, alcohol, ester, ethers, ketones, aliphatic hydrocarbons, unleaded petrol, motor oil, aromatic hydrocarbons, toluene, and DOT 3 brake fluid.

and more care is required for quality control and machine maintenance to prevent powder degradation, which could deteriorate part quality over time. HP 3D HR PA 12 in Fast mode was tested and resulted in brittle insoles.

Although total cost per pair when manufacturing with HP MJF technology may seem high compared with the price that some customers may declare during negotiations, when the full business picture is analyzed, the benefits are enormous. The following paragraph explains and quantifies the advantages in five axes:

## Product performance



A detailed study from the Instituto de Biomedicina de Valencia (IBV) compared PP with HP 3D HR PA 11 and showed a close comparison between materials. In other words, the dynamic stiffness of the material, the deformation energy recovery, and the maximum permanent deformation after 10^5 fatigue cycles mimic the behavior of the most common CNC PP currently used in the market by only adjusting the insole thickness (screening tests carried out at IBV with CNC PP, HP 3D HR PA 12 Balanced, and HP 3D HR PA 11 Fast insoles). PA 11 elongation allows for strong flexion of the insole without breaking or producing minimal deformations, which means the insole will recover its original shape. In addition, PA 11 results in **improved water elimination**, **abrasion resistance,** and much **better gluing adhesion** to the cushioning cover than PP machined.

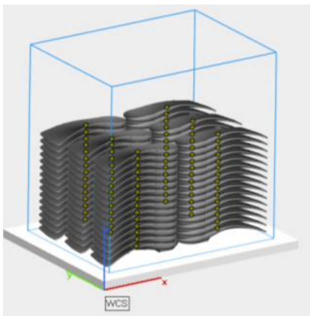
CNC-Machined insoles require a large amount of manual labor costs after machining (attachment removal, grinding, and polishing). This implies that all insoles may be slightly different in terms of dimensional accuracy (up to 1 mm), and when a customer asks for the same pair they had asked for months prior, it may be difficult to reproduce. HP MJF post-processing operations are negligible and therefore allow for **high repeatability within general tolerances of +/- 0.3 mm.** Like with CNC, with HP MJF, if cooling times are not respected, slight warpage can appear, but socks and weight will compensate these bridge deformations. A much tighter tolerance and repeatability are achieved in thickness which is very important to ensure rigidity consistency.

HP MJF's **design freedom** capabilities allow for the creation of products with variable thickness, local reinforcements, and better-looking shapes. This helps improve the performance of products by improving **flexion and making the product more lightweight** and **more innovative. A better grip with the shoe** can be achieved by applying textures to the lower surface.

In addition, tests for **heat forming adjustments** with thicknesses of 2 mm, 3 mm, and 4 mm have been performed with a heat gun and fresh air, allowing clinicians to make last-minute adjustments if necessary.

## Economic advantage

The total cost for HP MJF–produced insoles for a population with average shoe sizes using Balanced PA 11 will be approximately $14 per pair, depending on design, size, and machine utilization (shifts and nesting optimization).

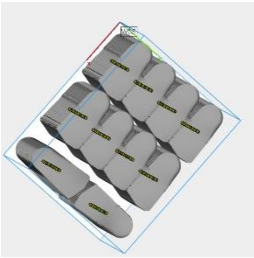



The average insole **cost per pair is $14 when using an HP Jet Fusion 3D 4210 Printer**. Fixed costs will be around $4.50 per pair and are mainly driven by machine amortization and the number of parts the machine can produce. Considering 220 working days with an average production of two build jobs (BJs) per day with a height of 250 mm and respecting a packing density (PD) of 12% for this special shape allows for the production of approximately 48 pairs per bucket. A maximum capacity of 21,200 pairs per year, per printer can be achieved. Fixed costs are calculated with a five-year amortization. **Variable costs** will be around **$9.50 per pair** and are mainly driven by the volume of the part and the percentage of refreshing powder required. This cost is true for average

parts that fit inside a boxing of 185 mm x 69 mm x 25 mm, which is the case for most of the sizes in three-quarter–hard insoles. For sizes larger than this boxing or full insoles, the cost will increase.
As stated in printing recommendations for these shapes in high PD, extra fresh powder may be required to compensate for any possible powder degradation. An extra 5% of refresh powder (35% total) would imply an increase of $0.50 per pair.

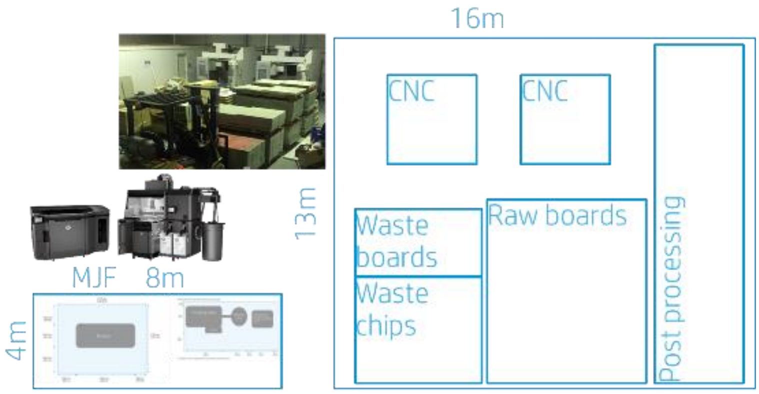
When using the fast mode on Pa11, if the customer is willing to reduce performance in exchange to cost, the better cost and capacity can be achieved. With the 4210b solution a capacity of 30.750 pairs/year and a cost of 9.46€/pair can be achieved when doing full buckets of 164parts per bucket.

**For small-sized insoles produced using HP MJF technology, the cost can decrease to $7 per pair.** CNC Machining and vacuum-forming costs are low depending on the size of the insoles, whereas the HP MJF cost decreases drastically when producing small-/medium-sized parts. Small insoles allow for the placement of more parts along the XY-plane and therefore more parts per bucket, thus decreasing fixed costs. As less material is printed, the variable cost will drastically decrease for parts with a boxing size less than 136 mm x 67 mm x 23 mm. This is applicable for small insoles (three-quarter–hard for **women and children**). A representative bucket for this population has been printed to fit up to 100 pairs of insoles in a 250-mm height bucket (PD 16%). This allows a capacity of 35,300 pairs per year with a total cost of $7. This is only applicable if only this specific size was produced, but it can provide an idea of the possible cost reduction for this population. Some customers may save CNC for very big insoles and launch a specific product for this population to start switching their production to HP MJF.



As stated before, the industry is accustomed to lower production costs for a lower performance product. However, when considering the big picture, price can be increased and costs reduced when taking into account the following points.

HP MJF is also much more **labor cost–efficient**. The total amount of time spent producing one pair of hard insoles can be 20 minutes to cut, grind, and polish, whereas HP MJF technology requires a maximum of 3 minutes per pair to load, unload, and introduce in the automatic blaster. Operating HP MFJ technology can take 4 hours per day whereas the equivalent CNC Machining team will necessitate three to four operators. Considering a low hourly operator cost of $20, this would mean **variable savings of $5.60 per pair in labor costs,** so HP MJF technology implies annual savings of $120,000 in labor costs.
HP MJF allows for the production of the same number of insoles while requiring **7 times less space in a manufacturing plant**. HP Jet Fusion 3D printers plus materials require 28 $m^2$ and produce as much as two high-productivity CNC Machines, which, with raw and waste material, would require 208 $m^2$. Considering a smaller warehouse with a low cost per square meter (e.g., $80 per square meter, per year), the annual savings would be approximately $12,600. This represents **fixed cost savings of $1 per pair**.



## Time

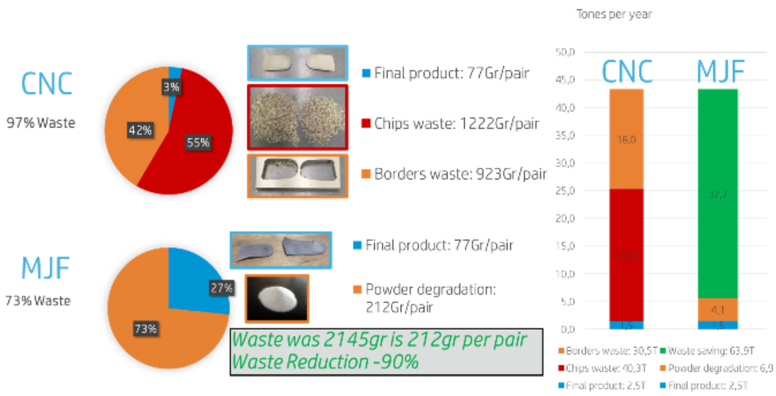
**Lead time is important in this industry.** Several insoles manufacturing companies engage with their customers to respond to queries within five working days as a normal policy, with an extra charge for shorter lead times. To adhere to this policy, printing and cooling must be completed in two days in order to finish assembly on the third day, allow a fourth day for margin, and to send the product on the fifth day. Jobs with **heights of 250 mm** that will print (12 hours) and using fast cooling (10 hours) provide a combination that most users prefer. This solution is achieved with **one printer, three build units, and one post-processing station**. Full-height jobs are possible if the total lead time to produce the printed parts is two days. For very urgent demands, it is possible to perform very short jobs by blocking the machine for 4 hours and delivering within two days. This should be done very rarely as urgent insoles will be more expensive to produce. Another possible option is the **HP Add On The Flight function** that allows you to add these urgent insoles to the top of the 250-mm running job at the very last minute.

## Personalization

A portion of the insoles are **custom-made** for sports, orthotics with high selling prices, and orthotics with high margins, depending on each country and market. The personalization market is growing in sports and healthcare. Compared with traditional manufacturing, HP MJF allows for the addition of **labels** to personalize the product for the customer, podiatrist, manufacturer, or others. The current insole market has a very similar product with the **design freedom for branding differentiation** with textures and design features. In terms of **post-processing without adding a huge cost,** HP recommends automatic abrasive approaches such as blasters or ink dyeing in dark colors (e.g., black, dark blue, dark red).

## Sustainability

Sustainability is one of the key factors for this industry. Current machining processes are inefficient as 97% of the material is waste, implying an enormous ecologic footprint. An average pair of 77 grams produces 1,200 grams of chips and 900 grams of lost borders. Insoles produced with HP MJF will produce under 100 grams of waste, including powder degradation. The machines used to 3D print with HP MJF will be able to produce up to 21,000 pairs per year, which means that **every HP MJF machine installed will save approximately 40 tons of material waste per year.**



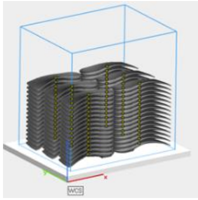

Although current waste may be recycled, treating this large amount requires a high amount of energy, labor, and transportation.

## Barriers of adoption

Customers could be reticent to adopt HP MJF technology because of the **large initial investment**. They may have been optimizing CNC Machining and other processes throughout the years, and their machines may already be amortized, removing most of the fixed costs. The investment in two CNC Machines is equivalent to one machine with HP MJF technology. Cheaper CNC Machines may exist in the market, but vibrations, tolerances, and tool path marks will generate a lower quality insole.

For custom-made insoles, the **design software** has a big impact on the cost. HP MJF allow for the production of a large number of insoles, but the designs must be tuned and adjusted one by one. Therefore, the time to produce, adapt, and generate the design is critical. Specific insoles software (SW) that generates STL files can process a design in 1 to 20 minutes, and faster SW will enable scalability for this application. HP is partnering with and recommending some of the available SW solutions to optimize this work and can connect players in this industry.

## ⚠ PRINTING Recommendations/Warnings



The **recommended printing orientation is flat** with the upper skin of the insole facing upwards, which is beneficial for productivity as more insoles can fill the bucket and it offers more height job flexibility. In the case of an interrupted job, the losses will be lower, as well. If customers want to prevent the stairstep effect, parts can be twisted 90 degrees. **Avoid vertical orientation** with the longest edge in the Z-direction as it is the worst direction for flexion and, therefore, for this application.

The most suited material for this application is PA 11. Customers are willing to reduce costs as much as possible, but the thermal behavior of the process has some limitations. Insoles are walls that will be placed parallel to each other, creating a shape configuration that looks like a radiator. This means that **with extremely high PD**, the powder surrounding the parts will be strongly affected by heat and **powder oxidation** is more likely to appear if you overpass some limits. Powder oxidation occurs when some polyamides are exposed to oxygen and excessive heat for a very long time. Low oxidation is not a problem for this application, but if this customer overpasses HP recommendations and this phenomenon occurs on a large scale, the elongation of some parts could be affected, reducing elongation, and parts may become brittle for big insole flexions.
HP has run extensive tests in serial production environments and productivity to evaluate the optimal point and find a good balance between quality, productivity, and costs.
Today the optimal point demonstrated with 42XX series has been found when respecting following limits:

-Use Balance mode
-Maximal job height of 250 mm
-Minimal distance between parts of 2 mm
-PD below 12%
-Use natural cooling → extended cooling will reduce warpage risk but imply more oxidation
-Fresh ratio of 30%

All of this has been demonstrated on over 20 consecutive buckets with a flexion torture test (out of normal usage) over 30 mm for a thickness of 3 mm with a 100% success rate. If a customer decides to overcome any of the parameters above, like increasing PD, they should do so gradually and control part quality impact for a long period of time (between one and three months). If needed, compensate by adding some extra fresh powder. It is recommended to always track powder (take samples that can be sent to a lab) and add flexural samples to every job in case of doubt or to make a periodical (monthly) control.

A trade-off must be considered between the fixed cost linked to a given productivity (PD) and the variable cost associated with refreshing with more powder. For this application, the fixed cost associated with producing fewer insoles per year is more important than adding 5% extra fresh powder.

It is important to avoid recycling the powder adjacent to the walls. Do not use brushes to recover this adjacent powder. By shaking parts, loose powder will fall, and the powder attached to the insoles can be separated from the powder to be recycled. This way, high-quality powder is kept in the recycling process and the more degraded powder is discarded.

In terms of nesting optimization, the best way to fit as many insoles as possible is to distribute as many layers of insoles as possible into organized columns and to avoid random positioning. It is not recommended to use automatic algorithms that can be slow without a powerful computer, but SW scripts can be associated with generic nesting SW available in the market.