Z Corporation:
Rapid Prototyping and 3D Printing

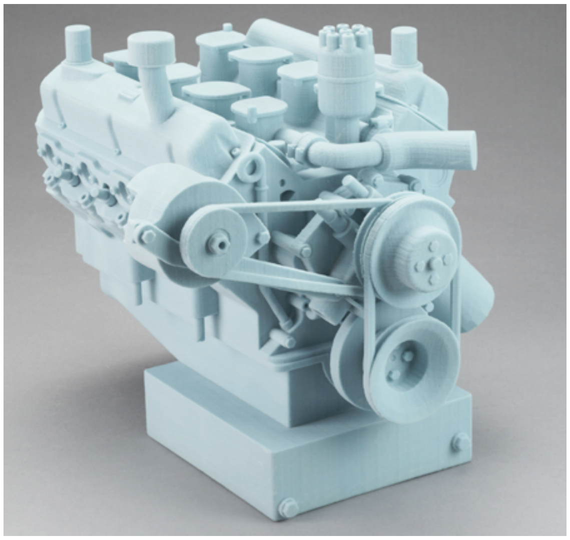
Marina Hatsopoulos, Former CEO

Company Background:

I was interested in managing a technology business. After a year of looking at hundreds of businesses, most of which were failing due to a lack of product differentiation, I finally found myself at the Technology Licensing Office ("TLO") at MIT. The TLO pays to patent inventions that are made by the professors and students and MIT, and then finds people or businesses to commercialize the technologies. This was an approach that got to the heart of my frustrations in looking at businesses with no product differentiation; by building a company based on a unique, patented technology, we could have product differentiation based on technology.

My partner and I were introduced via the TLO to the inventors of a technology called 3D printing. This technology uses a standard off-the-shelf Hewlett Packard ink jet print head to print liquid onto layers of powder, thereby fabricating physical prototypes layer by layer in a matter of minutes or hours. These prototypes could be used by designers and engineers to evaluate their new product ideas in their hand, instead of visualizing them on a screen or paper. I researched the market for this family of so-called "rapid prototyping" technologies and found that the existing technologies served only a small portion of the total potential market, because they were: 1) expensive ($100K-$1 million); 2) used expensive, often toxic materials ($500-$2000 for a typical handheld part); 3) required special ventilation and other features which put them in a lab or shop environment; and 4) were difficult to operate and required extensive training to learn to run.

There were three major competitors in the field at the time, all of which were publicly traded companies that were substantially bigger and better capitalized than Z Corporation. 3D Systems was the pioneer of rapid prototyping, having created the space a decade earlier with a laser-based technology that cures photopolymer resins. They had grown to be the largest company in the space, but had erratic profitability. They had been selling through a reseller channel, but had just let them all go and moved to a direct sales model. Stratasys was a significantly smaller company but more effectively managed, so that they had a record of profitability. They also sold their products through a direct salesforce. Their technology deposited a thermoplastic filament layer by layer to form a part. DTM, which also sold direct, was another competitor which had very large, expensive equipment (over $500K) that required a lab environment. They had a powder-based technology which used a laser to sinter powder together. We had studied their patents carefully because many of the powder-handling issues we faced had been confronted by DTM before us.


Example of Z Corp Prototype

The 3D printing technology that we saw at MIT was in a very early, crude stage of development. The prototype that the inventors had built used lots of duct tape, and it required two computers as well as a person to stand next to the machine and deposit a small pile of powder every 60 seconds during the build cycle. Our plan was to develop this machine into a commercial product, starting with an alpha design followed by two iterations of a beta design.

Our product specifications were designed to meet the needs of what we believed was a huge market for 3D printing, which were not being met by any of the existing technologies. These were attributes which were inherent to the core MIT technology and we believed would open up a much larger market than existed at that time. The attributes of our machine would set us apart completely from the competition. The specifications were:

- List price: $20,000
- Inexpensive materials: $20-$80 for a typical handheld part
- Office-compatible, located next to the designer's desk
- Non-toxic proprietary materials
- Easy to run-requires a few hours of training

- Fast: a few hours to make a part

We believed that the potential market for such a 3D printer could include any user of 3D CAD. There were well over 500,000 installations of 3D CAD at that time, leading us to believe that the market potential was enormous, although it should be noted that none of these CAD users knew what a 3D printer was.

Based on these specifications, in December 1994 we founded Z Corporation with the two inventors from MIT. We rented space and hired some engineers to help in the development, using our own limited personal capital to fund the business. Our goal was to sell our first commercial beta unit to an independent company by December 2006. A year into it, we had successfully built the alpha machine and were well into the design of the beta machine. In November 1995, the annual Autofact show was held in Chicago, and we went to see if there was anything new in the market.

At this show, 3D Systems and Stratasys both announced new products aimed at the same market we had targeted. We were devastated. They were office-compatible systems using non-toxic materials which were designed to be easy to run. These were companies which already had an installed base, lots of presence in the market, and a well established sales strategy. We still had a year left on our development, and not a single customer. We didn't even have a salesperson at that time. We investigated the products at the show and asked lots of questions. It turned out that their systems were simpler to use than ours, with less mess. Their part quality looked pretty good. However, they only showed small parts at the show, and when we inquired we discovered that our system was about ten times faster. So a typical hand-held part would take overnight on their system and just an hour on our system. We didn't know what to do.

The Assignment:

Your assignment is to imagine that you are Marina Hatsopoulos, getting ready for the upcoming board meeting.

1) What information about the competitors' products would you really like to know?

2) What are the various options available, and what are the tradeoffs of each of the options?

3) What are the highest priority factors to consider?

4) What are the biggest risks and biggest opportunities?

5) What do you recommend to the board?

Exhibit 1: Competitor Websites

www.zcorp.com

www.3dsystems.com (which later acquired DTM)

www.stratasys.com

Exhibit 2: Commercial Competitor Assessment from Z Corp's Business Plan

3D Systems

3D Systems, founded in 1986 and located in Valencia, CA, was the first manufacturer of stereolithography equipment and remains the dominant player in this market with a market share of 70%-90%. They had sales of $31 million in 1993, a 20% increase from 1992. Although their unit sales have dropped from a peak of 105 in 1990 to 45 in 1994, their price per unit has increased as they sell more of their higher-end models. They have sold about 435 rapid prototype systems since they entered the market in 1988 and they remain the only domestic manufacturer of stereolithography equipment.

The stereolithography process precisely directs UV laser radiation onto a bath of liquid photo polymer. The hardened material sits on a platform which is lowered deeper into the polymer bath after each pass of the laser. The various resins are produced by Ciba Geigy.

The SLA-190 product weighs 600 pounds and measures 27" x 49" x 64.5". The SLA-250 weighs 650 pounds and has the same measurements. The SLA-400 and SLA-500 each weigh 2841 pounds and each measure 72" x 136" x 80".

The SLA-250 has a helium cadmium laser, resolution of +- 0.005", a work space of 10" x 10" x 10" and sells for $110,000-$250,000 (depending on accessories). The SLA-500 has an argon ion laser, resolution of +-0.005", a work space of 20" x 20" x 24", and sells for about $400,000-$500,000. Their SLA-190 has a helium cadmium laser, resolution of 0.005", a work space of 7.5" x 7.5" x 9", and sells for about $100,000. New lasers cost about $10,000 and last about 2,000 hours. The workstation with the 3D slicing software sells for $30,000-$40,000; the software alone sells for $15,000.

The advantage of the technology is its very high resolution of detail and high strength; thus it is very well suited for small and functioning prototypes that simulate injection-molded plastic. This process is good for thin walls. Part strength is between styrene and ABS. However, these parts can't be used for functional prototypes under loads.

The primary disadvantages are its high cost and noxious chemistry. The equipment is typically set up in its own vibration-proof lab and requires process knowledge in order to produce quality products. Also, the waste stream is environmentally unsound and requires special handling. It ranks in the middle of existing technologies with respect to speed. The laser draw speed ranges from 15 inches/second for the SLA-250 to 100 inches/second for the SLA-500. A typical small part would require 10 hours to build; additional parts that fit within the build area can be made with a slight increase in build time. Cleaning, postcuring and finishing are needed for any stereolithography process. There is curing warpage and shrinkage. Also, it takes a day to change the resins, because the machine must be cleaned. Another disadvantage of this equipment is that buttresses, walls, columns and other supports must be designed into the part. Software exists that can do this automatically, however the supports must be trimmed by hand after production which takes from half an hour to four hours per part. Also sanding, plating and other finishing work is needed to give the part a finished look. Accuracy of parts from a service bureau are about 0.2% or +-0.002". The company considers Z-axis accuracy to be its biggest problem.

They have just announced a concept modeller to be sold for $50-60,000 in early 1996 with a focus on speed: 2x-4x faster than their other machines. It consists of a printer head with 96 jets spread over a 2.5" width which will spread a thermopolymer, layer by layer. The machine weighs 2000 pounds and is as big as a large copier: 6'x2'x3'h.

Sales for the first nine months of 1994 were $31 million, resulting in net income of $2.1 million. They have had increased interest in investment casting and have made 10,000 patterns in the last two years. 3D is involved in a patent infringement suit with EOS.

DTM

DTM (founded in 1986), located in Austin, TX, is majority-owned by BF Goodrich. Their process is called selective laser sintering. They started selling units in 1992 and had sales of 12 in 1994, for a total installed base of 50 units, according to Wohlers. Their Sinterstation 2000 equipment sinters powdered polymers in layers using a 50W carbon dioxide laser. The thin layer of powder is heated to just below its melting point and then the cross-section is traced by the laser which raises the temperature in order to fuse the powder particles. This process is repeated for each layer. The green part is then heated to high temperature, and then the porous metal part is infiltrated with molten copper.

They have recently introduced a fine nylon powder which produces an improved surface finish and crisper edges; other powders include metals and ceramics. Its system can produce wax patterns for a mold core cavity in order to cast a production-quality metal mold that can be used for injection molding. Accuracy is 0.002" to 0.010", and the work space is a 12" diameter cylinder 15 inches high (or 20" x 14" x 20" according to another source). The tolerance is +/-

0.010" initially or 0.005" on the second pass. DTM's process does not produce fine features, sharp corners or other geometric details with high resolution. The flexural strength is 4,800 psi for the polycarbonate material and 8,300 psi for the nylon material.

As with MIT's 3D Printing process, the loose powder provides support for the structure during building. A significant advantage of DTM's system is the variety of materials that can be used: most engineering plastics and standard investment casting waxes as well as metal powders for injection-mold tooling. DTM's equipment produces the strongest parts of all the competitive rapid prototype options. Along with Stratasys, their build rate is more than twice that of Helisys and Cubital; it is about 1/2- to 1-inch per hour. Also, additional parts can be built at the same time for a less than proportional increase in time to build. Also, their software accomodates adaptive slice thickness whereby the slices are made thicker on relatively straight areas in order to increase build speed.

The primary disadvantage is the high sell price of the machine, which is about $340,000-$400,000. Nylon and casting wax initiation cost an additional $60,000 and $80,000, respectively. The yearly maintenance is $85,000-$95,000, depending on the number of materials used. In addition, the requirement for attended operation and cleaning adds to the cost to build a part. The machine requires a nitrogen supply of 1.5 cf/minute, 50 psi minimum, as well as outside venting of toxic gases. The cost of the materials is about $65 per pound. Other disadvantages are questionable resolution in the z-axis. Layer thickness is 0.005 inches. The surface finish is grainy and is typically sanded or coated; post-process finishing is required. It is apparently easier to get a good finish on a stereolithography part than a DTM part, although the DTM part is better for functional testing. The Sinterstation 2000 weighs 4500 pounds and measures 4.9' x 9.6' x 6.3'. DTM machines are located in six domestic service bureaus. Sumitomo Group serves as DTM's Asian service bureau and distributor.

DTM is expected to go public shortly.

Helisys

Helisys (founded in 1985), located in Torrance, CA, utilizes a process called Laminated Object Manufacturing ("LOM"). Their first sales were in 1991 and in 1994 are estimated by Wohlers to be 57 units, for a total installed base of 96 units. Their LOM 1015 machine creates the part out of layers of paper, plastic or composite coated with heat seal adhesives. They are developing ceramic and polymer composite materials as well as metals. The shape is then cut with a 40W carbon dioxide laser and the excess material is cross-hatched for removal by hand once the part is complete. Thus the part is supported during building. Also it experiences no thermal stresses, shrinkage or warpage. The wood-like part can later be sanded, polished or painted for a smoother finish. Accuracy is 0.005 to 0.010 inch, and the layer thickness of the three sheets bonded to form a triple layer is 0.009 inches. This is the best process for large parts. They also use adaptive slicing to optimize speed/accuracy.

Maximum part size is 15"x10"x14"H or 32" x 22" x 20"H. Their equipment is among the least expensive on the market at about $95,000 for the small LOM-2030 version and $180,000 for the large LOM-1015 version, and also the least expensive to operate. The materials are cheap, at $2 per pound for paper and $2 per square foot for polyester film which is more flexible. The large work space is the largest of current rapid prototype processes. Also, there are no exotic chemicals. However, other than Cubital, it is the slowest to produce a part. Cutting speed is up to 15" per second at best. Also, this process can not produce small intricate parts with the quality of other rapid prototype processes. It can not produce thin walls in the z-axis. Post-process finishing is required: removal of the excess cubes, sanding, varnishing and coating. Also, the equipment requires outside venting and cleaning. The process smells from all the smoke. The LOM-1015 weighs 1000 pounds and measures 44" x 39" x 45". The LOM-2030 weighs 2500 pounds and measures 81" x 60" x 57".

Helisys went public (NADAQ) in April 1996.

Sanders

Sanders Prototype is located in Wilton, NH. Sanders had their first sales in July 1994, since which time they claim to have sold 12 units. They claim that they will reduce their price to $15,000-$20,000 by 1998. Roy Sanders is their founder and CEO. E Systems currently owns 10% of this private company which it helped to develop. The desktop Model Maker system uses one ink jet print head to deposit the thermoplastic build material and a second print head to deposit a supporting wax. The system uses non-toxic materials and does not require special environmental controls. The hot liquid solidifies on impact with the cooler build surface. Then a milling cutter planes each surface prior to depositing the next build layer. The support wax is dissolved in an ultrasonic cleaner. The maximum build size is six inches on a side. File formats accepted are: STL, HPGL, OBJ, CLI and SLC. Their POGO software has automated support generation and file repair. They are doing development in order to deal with metals and ceramic materials.

The advantage of the Sanders machine is that it is non-toxic, desktop and relatively inexpensive. The selling price is about $70,000, or down to $15,000 in orders of 1,000 units or more according to Sanders. Also it can produce small detailed parts with a very smooth surface finish to within 100 micro-inches. Sanders parts are better for tooling than SLA due to better Z-axis accuracy, smaller radii, better surface finish and the fact that parts are easier to finish. The accuracy is 0.001 inches/inch.

The major disadvantage of the Sanders machine is the very long build time. Small parts take 4-20 hours to build. The "slicing" software also takes a long time and can not operate simultaneously with the building device. In addition, there are certain geometric limitations and the finished part is not very strong. Small pieces in particular are weak. Sanders is still in the early stages of development and has only sold 12 or so machines. Although it is called "desktop," it does weigh about 200 pounds.

Stratasys

Stratasys (founded in 1988) is located in Eden Prairie, MN. Their first sales were in 1991 and have reached about 29 units in 1994, for an installed base of 66 units. There is a five-year agreement to jointly develop materials between 3M and Stratasys. Their 3D Modeler fused deposition modeling ("FDM") process system builds each layer of the part by extruding and laminating a thin 0.05" thermoplastic filament. The nozzle is positioned with a robot-arm and the thermoplastic is heated just above its flow point so that is solidifies as it exits the nozzle. A second material, which is weaker, is used to build support structures as needed; these are removed by hand after the build is complete. This process is somewhat similar to that of IBM. Materials currently are a durable plastic polymer; investment casting wax; machinable wax; or polyolefin. The wax parts are not as durable as the plastic parts and require twice as much time to build.

Their process is safer than the stereolithography machines since there are no unusual chemicals, polymers, fumes or lasers. The machine is small enough for an office environment, at 30" x 36" x 68". Also, no vents, transformers or special equipment are required. There is no cleaning, no waste, and no post-curing. Their process can create a wax model which can be used to create ceramic shell molds to later investment cast in steel. Accuracy is +-0.005", and the work space is 12" x 12" x 12". Wall thickness is 0.009" to 0.25", and the speed is 15 inches of filament per second. Their high-cost system with 3D Modeler and slicer software sells for about $200,000. The materials are less expensive than stereolithography, with a typical part would require $5-$9 worth of material, which is much closer in price to the Candy Machine than any other process.

Their process has very low maintenance costs. Although the process can be made faster, this results in inferior surface finish and resolution. At its best the surface finish and small features are not equal to those of other systems. Its FDM 1000 is a bench top model which sells for $70-90,000 plus an additional $7,000 for software. The FDM 1500, which uses four materials, sells for $62,000 (not including software). We need to find out if their low-cost versions are as fast as the more expensive version. They intend to sell a desktop version for $45,000 in 1995, but have not done so yet.

The disadvantages of this system are the geometric limitations; for example it can not produce square corners. The company considers speed to be its biggest limitation; with just one nozzle, the machine is quite slow. Supports must be added either manually or with software. Also, the underside of the finished part is not finished. Finally, the surface finish is inferior to that of Cubital. Post-process finishing is required. The 3D Modeler weighs 750 pounds and measures 30" x 36" x 68", while the FDM 1500 and FDM 1000 each weigh 250 pounds and each measure 26" x 34" x 34".

Stratasys is a public company, and raised $16.5 million in 1995. Sales in 1994 were $3.8 million, a 61% increase from sales in 1993 of $2.4 million. The net loss for 1994 was $1.13 million; their losses have been roughly $1-$1.4 million per year since 1991. Its gross profit rose from 54% in 1993 to 57% in 1994.

Stratasys recently acquired IBM's RP technology for $500,000 in cash and 500,000 restricted share of Stratasys. They pulled the three IBM alpha products out of the market and intend to incorporate the IBM technology which has similarities to the Stratasys technology; they will not sell separate ex-IBM units. IBM had planned it to be desktop-size and to sell for under $50,000. The equipment size is 26" x 34" x 34" and the process made parts that were useful as appearance models. This equipment extrudes non-toxic thermoplastic (similar to a hot glue) which hardens as it cools. The system can produce a part from CAD data, computer-aided tomography or scan data. They use a pump-and-nozzle assembly in order to change modeling materials quickly. The three materials that will be available will include one that can be a mold material for investment casts; another that will be a more flexible elastomer; and a third that will be hard enough to be machined. The maximum part size is 10" x 8" x 4.5". Accuracy is +-0.006"; the bead size varies from 0.009" to 0.033". The advantage of this process is that it can be very fast for hollow shapes. The disadvantage is that it is inherently more expensive than the Candy Machine and that there are even more severe geometric limitations than that of stereolithography. Also support structures are needed, so IBM had software that will automatically design these in during building.