Simplifying the Manufacturing Infrastructure for Maintenance and Spare Parts

Rick Lucas
Chief Technology Officer
The ExOne Company
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<td>Binding</td>
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ExOne Company
Overview

- Leading manufacturer of binder jetting 3D printing solutions to a global industrialized customer base, including:

<table>
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<th>3D printing machines</th>
<th>3D printed products</th>
<th>3D printing materials</th>
<th>Service, maintenance, and spare parts</th>
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- Industries served:
  - Aerospace
  - Automotive
  - Decorative/Art
  - Education
  - Energy
  - Foundries & Pattern Shops
  - Heavy Equipment
  - Pumps and more

- Approximately 300 employees worldwide
- Experiencing rapid growth and adoption of the technology
- 2018 revenue = $65 million: 12% year over year growth vs. 2017
- Three-year annual growth = 17%
## ExOne Business Units

### Direct Printing
Machine design and manufacturing for fine metal and ceramic powder applications. Metal commercial products for qualified materials.

### Indirect Printing
Machine design and manufacturing for mold and core making. Sand industrial products.

### New Markets
Wash-out Tooling for Composites
Traditional versus 3D printing supply chain

Article
Impacts of Additive Manufacturing on Supply Chain Flow: A Simulation Approach in Healthcare Industry
Eren Ozceylan 1,*, Cihan Çetinkaya 1, Neslihan Demirel 2 and Özsan Sabriioğlu 3
Conclusions

On a strict unit cost comparison, 3D printing cannot compete with traditional manufacturing at scale, so the question one has to ask is: what benefits does it offer in terms of responsiveness and customization, as well as reducing operational complexity?
Industrial Systems and Processes Needed to Disrupt Current Manufacturing Infrastructure

Only full blown Industrial systems have ability to supply high quality parts to a standard competitive with current manufacturing methods and processes.

*PC Magazine top rated 3D printers for 2017

<table>
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<tr>
<th>Printer Type</th>
<th>Price</th>
<th>Platform</th>
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<tr>
<td>Formlabs Form 2</td>
<td>$3,499.00</td>
<td>Amazon</td>
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<tr>
<td>LulzBot Mini 3D Printer</td>
<td>$1,250.00</td>
<td>Amazon</td>
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<tr>
<td>MakerBot Replicator Desktop 3D Printer</td>
<td>$2,488.03</td>
<td>Amazon</td>
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<tr>
<td>XYZprinting da Vinci Mini</td>
<td>$1,399.95</td>
<td>Amazon</td>
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<tr>
<td>Flashforge Finder 3D Printer</td>
<td>$283.03</td>
<td>Amazon</td>
</tr>
<tr>
<td>MakerBot Replicator Mini Compact 3D Printer</td>
<td>$499.00</td>
<td>Amazon</td>
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<td>New Matter MOD-t 3D Printer</td>
<td>$899.00</td>
<td>Amazon</td>
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<td>Robo 3D R1 +Plus</td>
<td>$399.99</td>
<td>Best Buy</td>
</tr>
<tr>
<td>Ultimaker 2+</td>
<td>$799.99</td>
<td>MSRP</td>
</tr>
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<td></td>
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Home Use Systems

Full Blown Industrial Systems
Simplifying the Manufacturing Infrastructure for Maintenance and Spare Parts:

Binder Jet 3D Printing for Sand
Conventional vs. Digital

- No patterns or tooling.
- 3D printed cores and molds using digital files and digital equipment.
When to Deploy the Science?

**Analytical - Science**
**Art - Experience**

**Digital Environment Enables Increased Velocity and Knowledge Capture**
When used properly, accurate simulations can provide physical insights that would have taken years of experience to acquire empirically.

The digital environment...facilitates the process of relearning “tricks of the trade” and “rules of thumb” that are being lost by the retirement of craftsmen and knowledgeable engineers.
Digital Technology Drives out Defects Faster

Analog Process

Time to first pour | Time to delivered part

Digital Process

Time to first pour | Time to delivered part

Main Gear Box Transmission
First Pour = No defects, part delivered
Morel Industries

Complex Digital Core Cuts Lead Time in Half & Saves Thousands
Morel Industries lowered their scrap rate from 9% to 1% and shaved three weeks off of traditional lead time.

Customer Challenge
Morel Industries needed a solution to eliminate the human error in the assembly of core boxes used with traditional wood and sand patterns.

The Solution
Working with a local pattern shop with 3D CAD knowledge and expertise, Morel was able to combine 3 cores into 1 printable ExOne core with vents and intricate geometry for their customer, North Harbor Diesel.

Conclusion
With ExOne’s digital printing process, 3 cores were combined into 1, decreasing the scrap rate from 9% to 1%. Lead times were reduced by 60% and costs were slashed by 85%.
Reduced Lead Time and Cost While Ensuring High Accuracy and Quality
ExOne® 3D printing technology reproduced damaged impeller with high efficiency.

Customer Challenge
Due to cracks and corrosion resulting from cavitation, the customer needed to replace a vertical pump impeller. The pump was over twenty years old and no longer in production. Without available spares, the customer urgently needed an identical replacement part while working with a limited budget.

The Solution
Additive manufacturing using ExOne® binder jetting technology to print a complete sand mold package in less than one week. This precise and efficient process ensured highly accurate blade orientation, minimizing post-casting machining time.
Complex Mold Production Reduces Lead Time by 9 Weeks & Saves Thousands

Customer Challenge
The customer required extremely fast lead time as well as complicated casting geometry for replacement cylinders on an old obsolete compressor. MW Smith DXP Engineers, contacted Pumpworks Castings, LLC about the need for 2 Compressor Cylinders on an expedited basis. The challenge; reduce lead time from an estimated 17+ weeks down to 8 weeks without tooling.

The Solution / ExOne Competitive Advantage
Using ExOne technology, Pumpworks Castings, LLC was able to meet the schedule by providing the old obsolete compressor heads to MW Smith DXP in 8 weeks. The complex molds were printed in about 7 days and it was estimated that using a traditional wood pattern to make this complex mold, it would have taken about 8-9 weeks. By using ExOne technology, the mold was made ready for the casting pour in about 1 week versus 8-9 weeks. By printing the complex mold in 1 week, the aggressive delivery of 8 weeks was met and the compressor repairs were started.
Cut Costs, Improve Quality & Shorten Lead Time on Production
The US Navy quickly and cost-effectively replaced tail cones for defense systems using ExOne® additive manufacturing.

Customer Challenge
Naval Undersea Warfare Center – Keyport (NUWC) needed a way to quickly and cost-effectively replace the tail cones of their MK 30 anti-submarine mobile targets.

The Solution
NUWC Keyport provided drawings of the part, which were quickly converted to a 3D CAD file. A local foundry designed and had the mold package printed in 12 days, using ExOne’s patternless sand printing method. After only 4 weeks, the completed castings were delivered to NUWC Keyport for a cost of $12,600 each.

ExOne’s Competitive Advantage
The completed castings met rigorous performance and nondestructive test inspection requirements. The result was that the US Navy was able to cut costs, improve quality and shorten lead time on production.
Reverse Engineer Compressor Pump Castings with 43 Week Reduction in Lead Time and 40% Cost Savings
The OEM quoted $29,562 each plus 51 weeks lead time.

Customer Challenge
Naval Undersea Warfare Center (NUWC) – Keyport learned of the need for vacuum cone castings used on Ohio-class submarines. There were none in their supply system. The OEM quoted $29,562 each plus 51 weeks lead time.

The Solution
The final castings were delivered to NUWC Keyport in 8 weeks for a cost of only $18,200 each. NUWC Keyport reverse engineered the castings in order to create 3D CAD files, which were used to print a sand mold package with the ExOne digital part materialization process.

ExOne’s Competitive Advantage
Additive manufacturing offers significantly shorter lead times and reduced component cost.
Simplifying the Manufacturing Infrastructure for Maintenance and Spare Parts: ___

Direct Printing Binder Jet 3D Printing for Metals... Can it be done?
What is Binder Jetting?

- Unique, binder-based 3D printing technology developed at MIT
  - Layers of material bond to form object
  - Liquid binding agent selectively deposited to join powder particles
  - Job box lowers, another layer of powder is spread, binder is selectively added; layering is repeated over and over

- Capable of printing a variety of materials – metals, sands, ceramics
  - Some materials require post-processing
  - Ability to print very large objects
  - No melting, welding or build plate – required for other 3D technologies
Process Comparison

Binder Jetting Affordability

Additive Processes
Independent studies conducted by UTEP and ORNL confirm that Binder Jetting is a clear winner in costs and addressing markets where cost is an important factor.

EBM and DMLS exhibited tiered, columnar grain structure created by the melt pool which is fundamental to these type of processes.
Future applications of Metal Binder Jetting from an automotive Perspective

Sinter-based Additive Manufacturing, Bremen, 19.09.2019
Additive Processes

**Binder Jet** part exhibited equiaxed grain structure leading to isotropic material properties. There was minimal chemical segregation at grain boundary due to the room temperature processing.

**EBM and DMLS** exhibited tiered, columnar grain structure created by the melt pool which is fundamental to these type of processes.
Binder Jet Process

1. Create a Digital File
2. Print the Part
3. Cure the Part
4. De-powder Part
5. Sinter the Part
6. Finished Part
MIM Market
Expands 3D/ MIM Market

Benefits Compared to MIM & CIM

1. No mold needed
2. No Injection mold and compaction press.
3. Short manufacturing times.
4. Simultaneous produce different parts.
5. Well suited for complex geometries.
6. Broad materials options
7. Ideal for short production runs
8. Can be used for small & large parts
Manufacturing Process for Spare Parts
Produced with Investment Casting Market

- Drawing Confirmation
- Tooling Design
- Tooling Making
- Wax Injection
- Clusters Assembly
- Slurry Coating
- Stuccoing
- Shot Blasting
- Gates Grinding
- Cutting Off
- Knockout
- Casting
- Baking
- Dewaxing
- Heat Treatment
- Inspection & Straightening
- Special Inspection
- Machining & Assembling
- Surface Treatment
- Final Inspection
- Packing & Shipping

Average Lead time 24 weeks
**Investment Casting Market**

**Lead Time Reduction**

**Benefits Compared to Investment Cast**

1. Lower CapX
2. Short manufacturing times
3. Simultaneous produce different parts.
4. Well suited for complex geometries
5. Broad materials options
6. Ideal for short production runs
7. Thinner wall sections
8. No tooling costs

*Average Lead time 24 weeks*

*Investment Castings*

*ExOne Binder Jetting*

*Average Lead time 1 to 2 weeks*
Industry 4.0 is a radically changed process for manufacturing companies. Data is gathered from all points of the process and evaluated and linked to production. Production processes react in real-time using new technologies such as sensors, next-generation robots, and 3D printing.
Engineered Particulate Infiltrated Composite

Cheap Raw Materials → Large Fast Flexible Material Printing → Post-Processing → Functional Tooling or Parts

Vacuum forming + Hydro Forming

Raw Sand Finish  →  Metal Plated
Ready To Paint  →  Cast-Cast Metallic
Smoothed Finish  →  Integrated Color

digitalbridge 2019
Pittsburgh’s Industry 4.0 Conference

CATALYST CONNECTION
Your Strategic Partner for Manufacturing Growth
Conclusions:

- Customers are demanding faster processing and better manufacturing infrastructure for maintenance and spare parts
- The existing supply chain continues to struggle with this challenge
- Because of economics and performance point of use manufacturing supply chain problems will limit the materials and parts that can be made with non-industrial systems
- Full blown 3D printing industrial systems will need to react in real-time using new technologies such as sensors and next-generation robots
- Binder Jetting is capable of providing the complexity, customization, quality, speed, and cost for the current and future factories of the future
- Data will need to be collected at all points of the process and react in real-time
- ExOne will continue to invest in the infrastructure and establish the factories of the future to address manufacturing infrastructure for maintenance and spare parts
QUESTIONS & ANSWERS

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