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AFS Industry 4.0 Survey

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ABSTRACT

Exploration of today's technologies defined by Industry 4.0 led to the AFS Industry 4.0 Committee conducting a comprehensive survey among AFS members employed in foundries, inquiring about the current state of Industry 4.0 practices in October 2022. The analysis of the survey responses provides groundbreaking insights and guidance for AFS and the foundry industry, highlighting the significance of Industry 4.0 in improving processes and maintaining competitiveness. These findings offer a unique understanding of I4.0 adoption and its impact on the foundry and casting industry, setting a benchmark for future advancements.

Keywords: Industry 4.0 (I4.0), Industrial Revolution (IR), Internet of Things (IoT), Artificial Intelligence (AI), data, sensors, integration, technology

INTRODUCTION

BACKGROUND OF INDUSTRIAL REVOLUTIONS

Early humans relied on having a broad skillset related to basic survival, such as hunting, gathering, and finding or making shelter. As humans began to domesticate crops and animals, societies began a lifestyle centered around farming. This shift allowed for greater food security and the growth of larger and more complex societies, eventually including specialized labor.

Expansion of the trades such as metalworking, woodworking, masonry, textiles, etc. combined with advances in technology further encouraged the division of labor, leading to the industrialization of the workforce and economic modernization.[1]

- Industry 1.0: The First Industrial Revolution (1760) transitions manual labor to machine-based manufacturing with the introduction of the steam engine.
- Industry 2.0: The Second Industrial Revolution (1870) presented new energy sources of oil and electricity, the assembly line, and widespread use of the telegraph and telephone. Notable names from this era include Rockefeller, Edison, Tesla, Carnegie, Ford.
- Industry 3.0: The Third Industrial Revolution (1969) introduces automation and computers to manufacturing.
- Industry 4.0: The Fourth Industrial Revolution (2011) takes automated and computer aided manufacturing to the next level with advanced technology detailed as follows.[2]

TOOLS OF I4.0

Industry 4.0 utilizes a range of tools and technologies that support the optimization of industrial processes.

Some of the key tools for I4.0 include:
<u>Robots</u> provide companies with the ability to automate processes and improve efficiency. They also provide an opportunity to remove people from hazardous workspaces and duties.

<u>Simulation</u> is a quick way to predict a variety of results such as stress testing, fatigue points, filling of a casting, solidification, and defect areas without the trouble of running time and labor-consuming trials.

<u>Vertical and Horizontal system integration</u>: Vertical integration combines the steps of the manufacturing process for a product and Horizontal integration expands across multiple product lines.

<u>Internet of Things</u> (IoT) connects machines and other devices which enables them to communicate with each other and share data. IoT can be used to monitor processes, gather data, and control equipment.

<u>Cybersecurity</u>: With all the ways to connect equipment, monitor work areas, and analyze data, it opens a potential for cyber-attacks. Companies improve their cybersecurity with the aid of firewalls, intrusion detection and prevention systems, encryption, and authentication methods.

The <u>Cloud</u> provides data management and storage capabilities for the immense amount of data being collected from the ever-growing number of sensors and IoT-connected machines. This allows for facile data access and communication.

Additive Manufacturing like 3D printing has risen as a popular process for prototyping and constructing complex internal geometries. It can be cost and time effective and with every day, more materials are being perfected with comparable dimensional accuracy to many traditional manufacturing methods.

Augmented Reality (AR) provides companies with the ability to visualize and interact with data in real time, making it easier to identify problems, optimize processes, and train employees.

Big Data: I4.0 generates vast amounts of data that can be used to inform decision-making, improve performance, and create new business models.[3]

DESIGN OF EXPERIMENTS

The Foundry 4.0 survey obtained 153 responses from AFS members working in foundries. Results for each question are shown as a percentage of the responses to that question. Some questions did not have all 153 responses. Several questions allowed for multiple-answer selections, resulting in a total percentage of responses that exceeds 100%. Reference to specific questions in the survey may be referred to as #[numerical value]. Graphics referring to specific survey questions have a corresponding number in the bottom right corner.

CONTENT

WHO WAS SURVEYED?

The size of foundries that responded to the survey are as follows:

- 8% have 1-25 employees;
- 10% have 26-50 employees;
- 21% have 51-100 employees; &
- 33% have more than 250 employees.

Note: Depending on the size and structure of the company, some titles and responsibilities aren't universal. Senior Management includes Director, VP, President, CEO, etc.

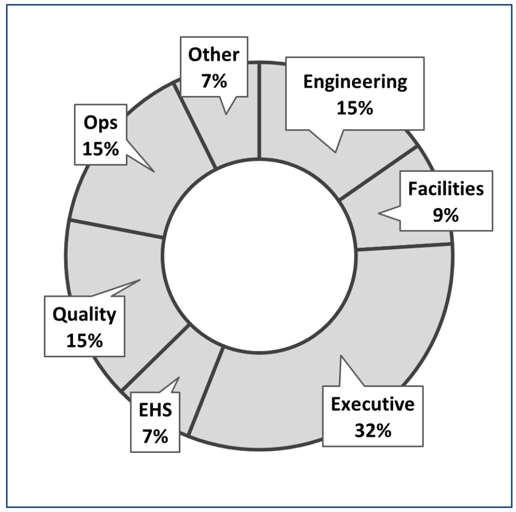

Figure 1. The distribution of job titles for survey respondents.

The largest category of responses in Figure 1 was from the director level or higher. Often, the people in these positions are active with AFS and have been throughout their careers. It appears the responses were mostly from people who are directly involved with the foundry operations whether it be engineering, maintenance, supervision, or management.

Since some foundries practice more than one molding process, the survey allowed for multiple process selections, Figure 2. Sand casting was by far the most prevalent (80%) and over 70% of those who selected multiple processes said sand was the predominant process in their facility. Following sand casting, was permanent/semi-permanent molding (15%) and shell molding (10%). Other methods mentioned were investment and lost foam, centrifugal, die cast, pressure cast, no-bake, and more. This diverse range of methods is important to remember when evaluating the results of this survey. The different methods make for a variety of eases and struggles in implementing I4.0 technologies and practices.

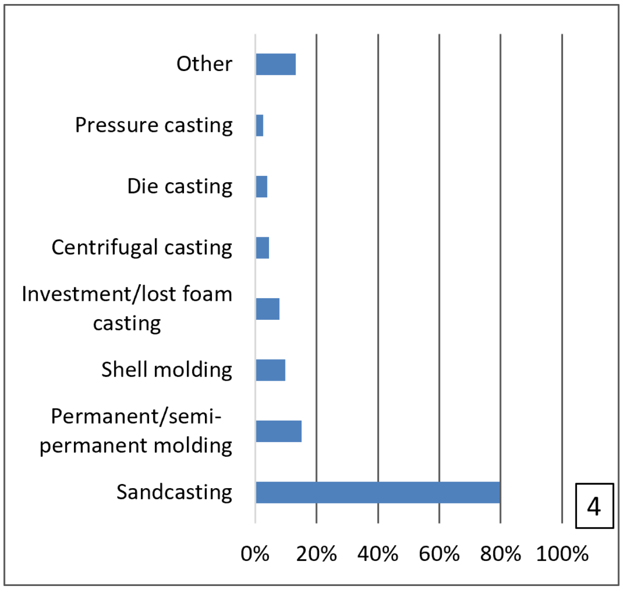

Figure 2. The different foundry processes practiced among survey respondents for question #4.

STATE OF I4.0 IN FOUNDRIES TODAY

Many departments are involved with the implementation of I4.0; most prominent are Management 71% and Engineering 62%. About one third of responses included IT Management, Maintenance, and Quality. When asked who leads I4.0 initiatives, Management and Engineering stood out again. Considering the main tools for I4.0, it may be interesting to see IT at only 30%. However, when considering over 1/3 of foundries responding have less than 100 employees some may not have large IT departments or other resources to dedicate to I4.0 as others.

Over 50% of responses listed current utilization of additive manufacturing, data analytics, data storage/cloud, sensors/IoT, automation/robots, or simulation.

Additive manufacturing can reduce tooling lead times, especially with the ease of use for many 3D printers and printing software. The wide private use of 3D printers has created large support communities and many economical options. The more people buy and use 3D printers, the better printers and software get with help from a huge pool of feedback to the manufacturers.

Data analytics can be as simple as charts made from basic software many companies already have, or complex self-analyzing software. It is important to know that for many sets of data, the output is only as good as the input and the people reviewing the outputs must have a deep understanding of the inputs to make astute decisions. Automation/robots had the highest priority of technology (21.36%) followed by sensors/IoT (16%) and Data analytics (14%). The second priority followed the same trend, but with higher deviation. Automation/robots and data analytics seem to be the overwhelming priority when it comes to current I4.0 technology in foundries. Some reasons for these results could be a struggle to hire and keep people in the foundry, higher demand for product(s), wanting to decrease lead times by running more hours with fewer direct resources, removing people from monotonous and dangerous jobs, standardizing processes results affected by human error, etc. Data analytics helps all sizes and types of foundries. It gives insights to historical and future trends to make data-informed decisions. Collecting data is still mostly done manually as almost 80% of responses indicate in Figure 3.

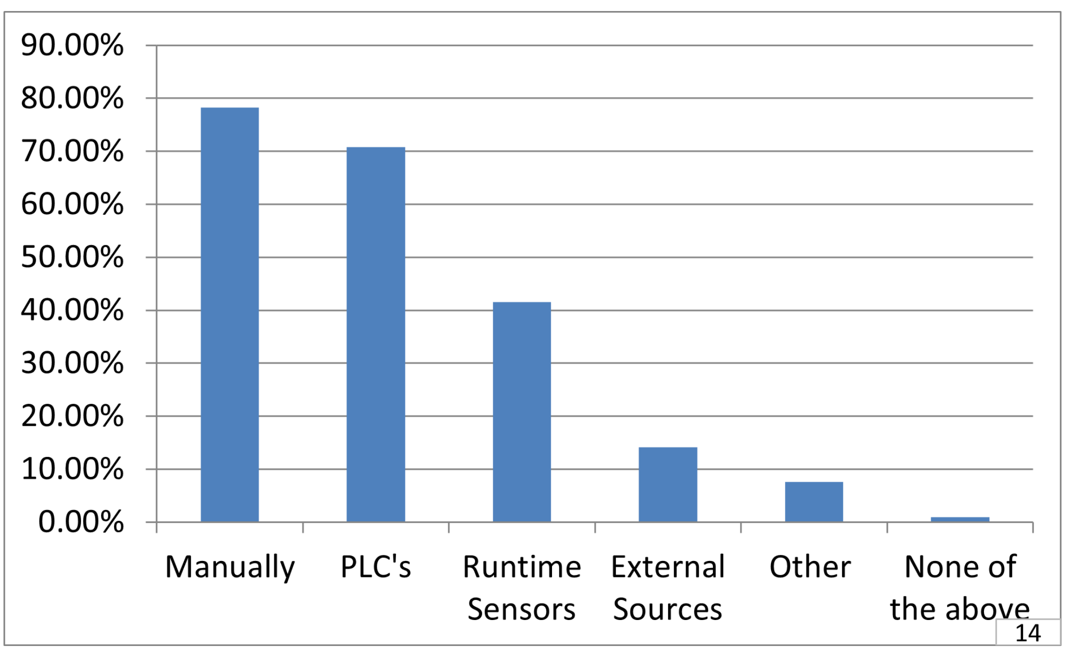

Figure 3. This bar chart categorizes how foundries currently collect data among survey respondents for question #14.

Manual collection usually consists of observing or performing tasks and writing the results down for tracking or analytical purposes.

Just over 70% of responses indicate the use of Programmable Logic Controllers (PLCs) to collect data. The PLCs can receive data from inputs such as sensors, switches, and buttons. Other inputs include encoders, potentiometers, load cells, vision systems, and Radio Frequency Identification (RFID) readers. Encoders and potentiometers can measure position via digital or analog inputs, load cells can measure force or weight (hence "load"), vision systems (which usually involve an optical input translated by software) could perform automated inspection, and RFID readers use radio frequency to read data from an RFID tag such as part information or location.

Though most foundries collect data manually, 51% of respondents said PLCs are the priority in a follow-up question. This could be due to the ease and amount of data that can be collected when compared to the time and resources required to collect data manually.

Foundries collect data in a variety of places. Over 50% of responses suggest currently or planning on collecting data in each of the following places: facilities/maintenance, melting, pouring, sand system, molding, cleaning/finishing, and quality. The priority of these sites could be synonymous with the level of control desired at each site. Melting and pouring data involves temperatures, metallurgy, heat and pour schedule, etc. Molding and sand systems could be seen as the second priority, remembering that not all foundries use sand. Molding could be inclusive of investment and die casting. While there is a lot of data to be collected, it can be more difficult to control. Factors such as temperature, humidity, time, wear of media and dies, etc. all have to be considered when evaluating adjustments using data collected.

The majority of surveyed companies are utilizing data and statistical analytics (74%) and runtime and cycle reports (58%). Maintenance reports (47%) and the use of Overall Equipment Effectiveness reports (47%) are common in the industry. Providing visualization to employees for operational/situational awareness (43%) to drive their operations and product, gating & rigging optimizations (41%) are also important use cases. Generating predictive business insights (28%) and enhancing environmental and safety controls (27%) are relatively less common. The use of machine learning (11%) and artificial intelligence (5%) is still relatively low, while the use of digital twins (5%) is the least common among the listed technologies.

Digital twins are often used by manufacturing to simulate multiple iterations without requiring the physical resources like materials and assembling. For example, an engineer can digitally replicate a cell or entire factory to optimize layout and efficiency of resource utilization. Figure 4 shows the most commonly used tools for data analysis and visualization are Excel (63%) and Enterprise Resource Planning (ERP) systems (46%). Other commonly used tools include in-house developed tools (37%), statistical software (32%), and data visualization software (30%), while machine Original Equipment Manufacturer (OEM) platforms (14%) is utilized less frequently. The "other" category (7%) includes tools not mentioned in the original list. It should be noted that 1% of respondents selected "none of the above," meaning they do not use any tools for data analysis and visualization.

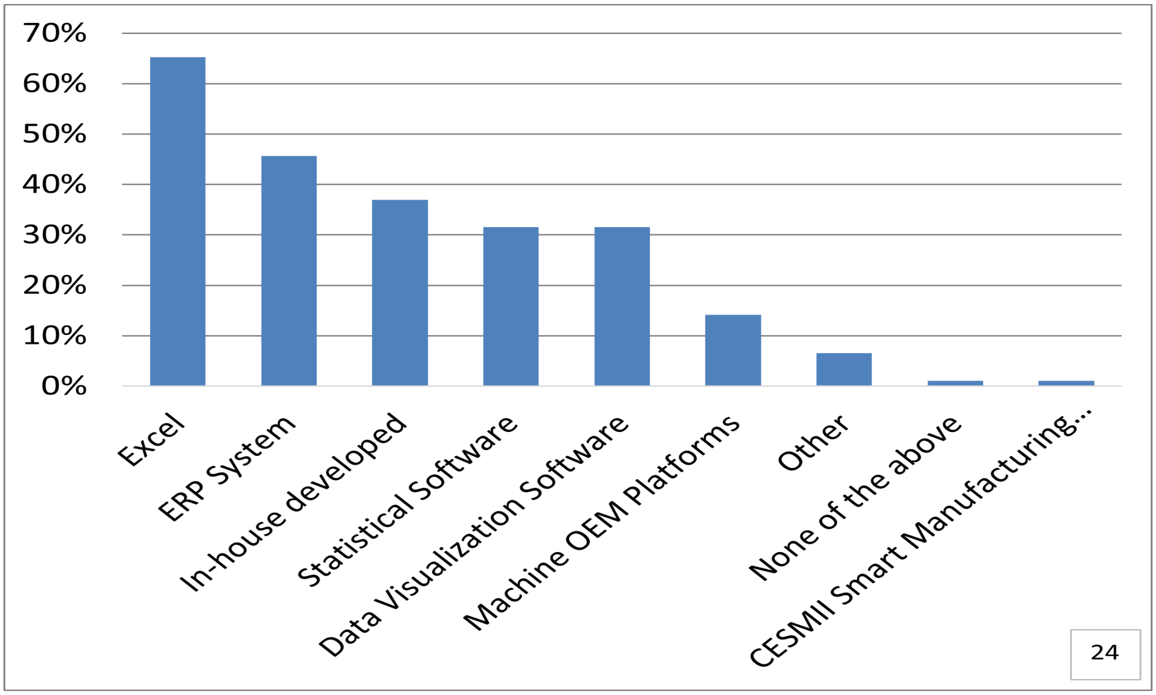

Figure 4. This chart shows the most commonly used tools for data analysis and visualization among the foundry respondents in response to question #24.

Though Excel is the most used currently as 65% of respondents indicate, the responses to the follow-up question #25, the most important tool for data analysis and visualization seems to be "ERP system" (31%). It is worth noting that some respondents left comments indicating that they consider different factors to be important when selecting a tool for data analysis and visualization. Some of these factors include user-friendliness, the ability to capture and format data as needed, and integration with other systems (APIs: Application Programming Interface). Others emphasized the importance of having a culture of data-informed decision-making and the role of data visualization in providing insights and training to employees.

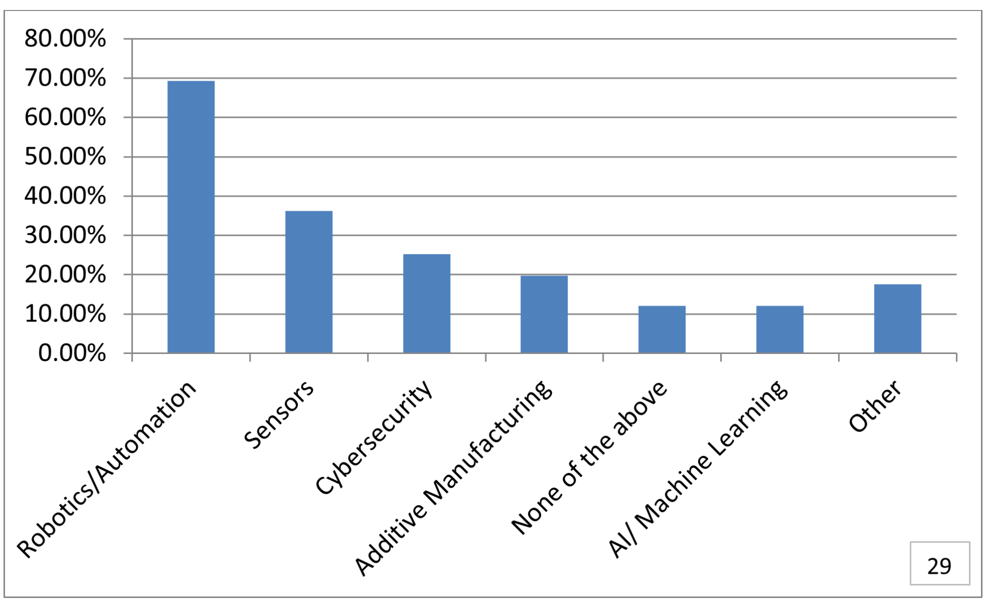

Figure 5. Survey question #29 asked companies how they have prioritized capital expenditures in equipment.

Though the highest priority for capital expenditure is robotics and automation as shown in Figure 5. Participants also indicated robotics being the top underfunded capital expenditure.

Most underfunded areas:

- Robotics: 25%
- New and enhanced Capabilities: 23%
- Operating Efficiency: 22%
- Cultural change: 22%

Underfunding in human capital to implement projects, support for automation integration, and human management were also mentioned. Most responses thought none of the options listed were underfunded. Figure 6 shows similar interest in focusing effort into robotics and automation over the next three years.

BUSINESS NEED BEHIND I4.0

89% of participants want to use I4.0 to increase throughput and efficiency. Over 72% want to reduce defects and increase quality. Over 50% want to use I4.0 to reduce downtime and automate reporting. By automating dangerous or repetitive tasks, I4.0 technology can mitigate the risk of workplace accidents.

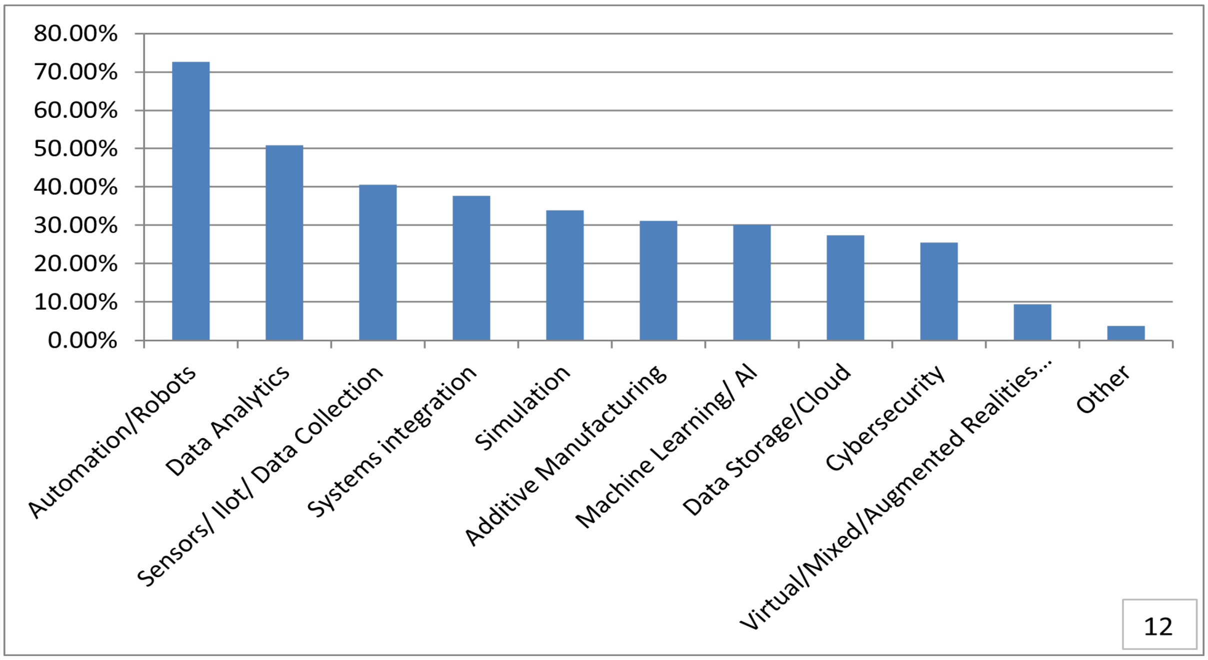

Figure 6. Question #12 shows the areas of focus over the next 3 years among respondents.

With access to real-time data and advanced analytics, I4.0 can provide companies with valuable insights into their operations, enabling better decision-making and improved performance. The I4.0 technologies can help companies reduce waste, optimize energy use, and minimize their impact on the environment. The use of IoT and data visualization software can assist companies in supply chain management, enabling them to reduce lead times and allocate resources more effectively.

Foundries would like to measure a variety of variables related to their production processes, equipment, and materials to improve quality and reduce scrap. These variables include root cause analysis for determining the root causes of quality issues and defects to develop strategies to fix problems.

Monitoring equipment and identifying issues early through predictive maintenance is another key variable which will tie in with tracking downtime and maintenance causes to reduce the impact on production. Sand properties are a major variable of many foundries. Monitoring sand properties, such as green strength and moisture content, ensures optimal casting conditions. Identifying process trends by analyzing historical data aids in identifying changes that may impact quality and production. Foundries are also looking at motor and sensor monitoring that uses data on motor and sensor performance to predict and prevent failures. Figure 7 illustrates the areas most likely to be enabled to collect more data in the future.

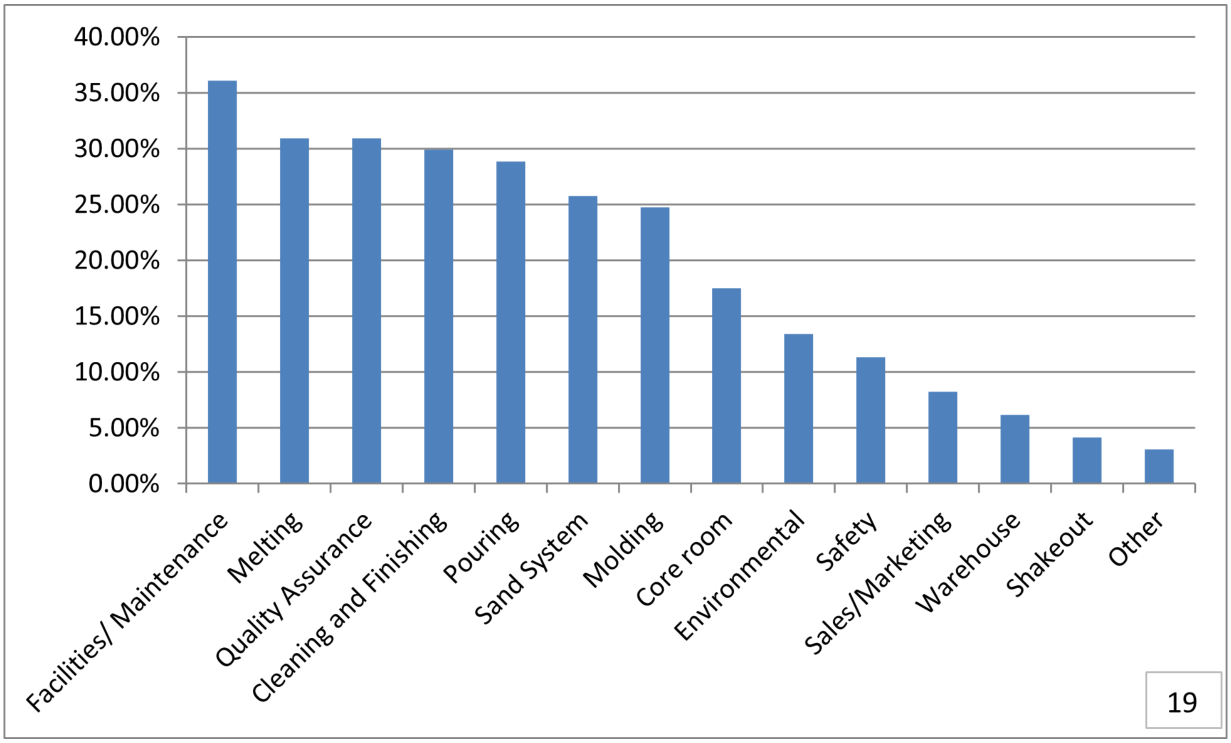

Figure 7. Question #19 asked participants to select the three areas most likely to be enabled to collect more data in the future.

Between robotics/automation, additive manufacturing, cybersecurity, AI, and sensors, the survey results reveal that the clear priority investment for the imminent future in foundries is robotics/automation, with 63% of respondents choosing it. The other categories received less than 10% each in terms of investment priority. This preference can be attributed to the proven track record and subject area knowledge surrounding robotics/automation, while technologies like AI still carry uncertainties and concerns regarding exploitation. One of the prominent challenges faced by current facilities is the workforce shortage, which can be alleviated by robotics and automation. These technologies can fill vacant positions, make tasks easier and safer for operators, and potentially reduce turnover. Operating efficiency and quality were identified as the top concerns, and robotics/automation provide consistent performance and measurable results, making troubleshooting simpler. However, it is important to exercise caution when relying on robots and automated cells due to their inherent limitation of lacking autonomous decision-making capabilities without extensive programming.

BARRIERS TO I4.0 IMPLEMENTATION

It is important to look at the difficulties when implementing I4.0 to appreciate the efforts that need to be made to bring foundries to the same place as other manufacturing environments. Environment plays an enormous factor in the ability to advance. Electronics, vision systems, and robotics are not typically well-suited for dirty and hot conditions. Automation is more easily justified when there is little variety and high volume. Size of company, foundry processes, and even alloy could affect the types of hurdles experienced.

When surveyed, the following were found to be hurdles in the adoption of I4.0:

- Lack of qualified employees (51%)
- Lack of labor required to implement (38%)
- Cost justification (38%)
- Finding external expertise to implement (15%)
- Available capital or financing (26%)
- Technology not proven (10%)
- Don't know where to start (11%)
- Lack of support from other departments (13%)
- Don't see the need (9%)
- Other (9%)

Other hurdles mentioned include:

- Time to implement
- Need for continuous employee training
- Lack of knowledge about I4.0
- Need for customized solutions
- Difficulty in scaling solutions across plants

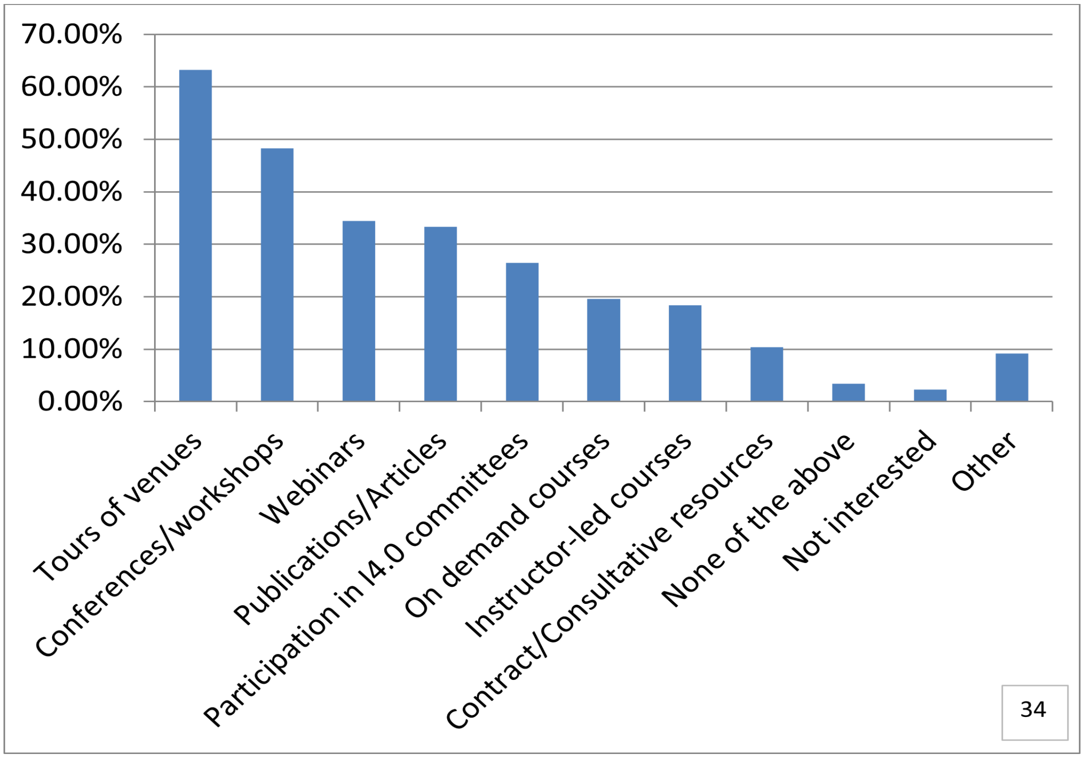

Figure 8. Question #34 asked foundries what would help most to broaden their Industry 4.0 efforts.

Though tours scored higher on question #34, Figure 8, respondents would prefer to see AFS research and education put toward conferences and workshops with presentations by accomplished practitioners according to question #35 asking what the priority should be in the future (28%). Tours had the 2nd highest priority rate (24%), which could be due to the ability of people to schedule foundry tours without outside aid.

Some of the benefits of touring other facilities in person are the ability to see equipment integrated into a process, make strong personal connections, and sometimes while a person is going to look at one process, they see another process that becomes valuable knowledge later on. For the mechanical mind and hands-on learners, this approach to gaining information is helpful. When bringing production workers on a tour of another foundry, this mutually beneficial experience gives the employee perspective of other methods and processes while enabling feedback from that person to the host. Conferences and workshops provide the opportunity for instant feedback from people with diverse experiences and knowledge. It presents a structured, yet interactive learning environment.

Webinars and virtual and on-demand courses are convenient for many folks. It cuts out the time and cost of traveling, whilst providing valuable information.

Publications are an incredible resource that many could argue is undervalued and underutilized. While many foundry-related publications are decades old, they still find relevance in today's foundries. The convenience of publications is that often, you don't need internet connection. Perhaps to find the article initially, but most publications can be downloaded or printed and read whenever, wherever, and however much of the article the reader wishes.
In the other response section, respondents mentioned learning more information involving I4.0 in general and specific case studies being helpful. This would be especially helpful if the scenarios involve overcoming challenges such as low volume, high variety, uncommon alloys or manufacturing processes, etc.

As shown in Figure 9, most respondents would like to see management at their company get involved with I4.0 efforts.
Maintenance, Quality, and Engineering received over 40% of responses. Over 30% of responders marked supervisors and IT.

While many I4.0 methods are implemented by the secondary and tertiary groupings of responses, management is commonly the approver or negater. There are many facets I4.0 tools cover so communication between individuals and departments must be clear and efficient. This would be facilitated by management.

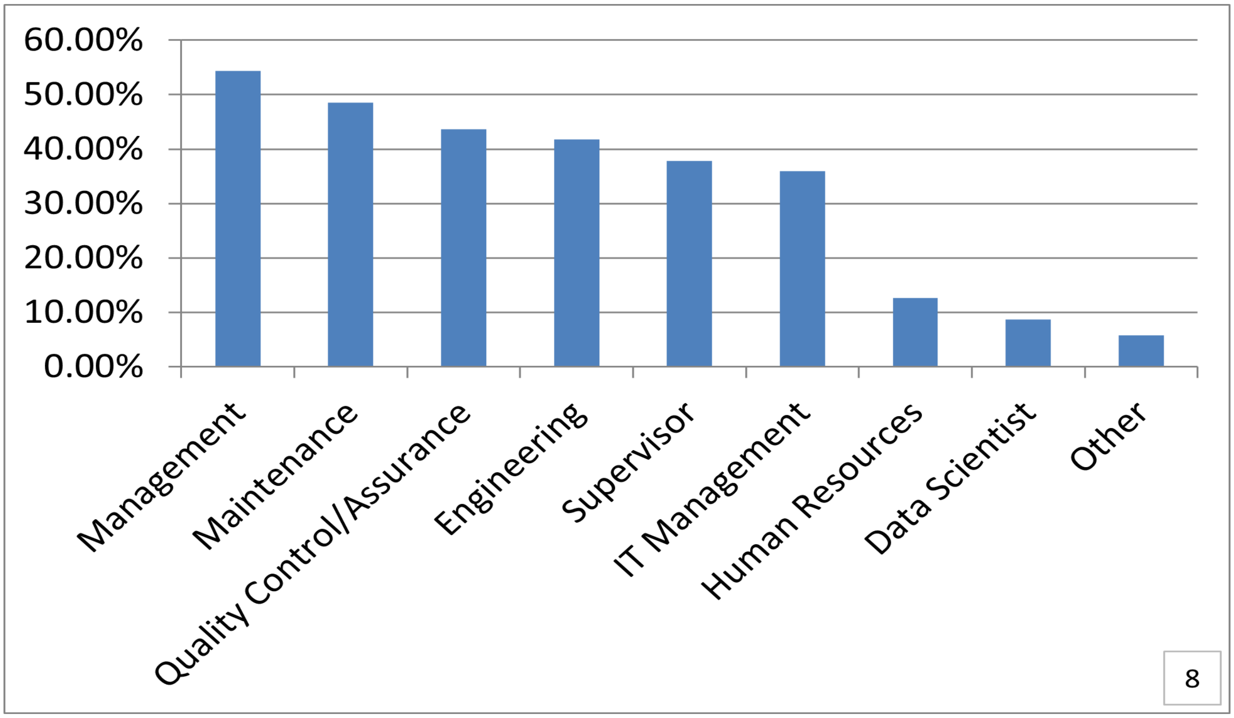

Figure 9. The survey asked foundries who they would like to see get involved with their Industry 4.0 efforts.

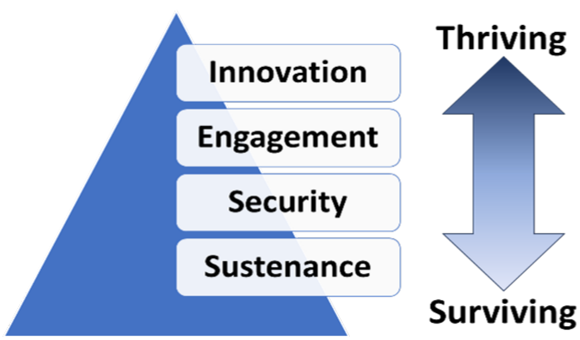

Figure 10. This diagram demonstrates an adapted version of Maslow's Hierarchy of Needs as it relates to industry.

CONCLUSIONS

It seems as though for many foundries, the two major causes for not already largely integrating I4.0 is a lack of knowledge for what is out there and how to do it. The adaptation of Maslow's Hierarchy of Needs in Figure 10 shows the importance of needing to first ensure that the basic needs of the foundry are met to operate and survive before moving on to more advanced workplace needs and improvement.

Maslow's Hierarchy of needs explains a person's ability to go from surviving to thriving in life. At the simplest level is the bare essentials required for survival such as food and water. After this condition is met, humans need to feel safe in order to learn. Humans need to have knowledge to move to a higher self where they discover their "purpose." This model can be adapted to foundries. In order to operate a foundry, there must be materials like metal, sand, energy to melt the metal, etc. Once this "sustenance" is fulfilled, foundries focus on creating a safety culture and a stable supply and demand. This is "security" for the operation of the business. Companies can then focus on "engagement" in the workplace: employees know and understand the process and are actively involved in making decisions for general operations. When general operation is nailed down, "innovation" can germinate. Once the basic needs are met, foundries can move up the pyramid into thriving businesses.

As technology becomes more widely used it becomes easier to use, more affordable, and generally more common in the industry. Unfortunately for many, it may come to the point where foundries must adapt or die. While foundries will continue to operate, it becomes more difficult to compete for labor and talent. Benchmarking off other manufacturing processes may not seem a fair comparison, but there has already come a point where foundries are competing for the same resources and sometimes even product market.

As mentioned earlier, it may be more difficult to integrate I4.0 in foundries than in other manufacturing facilities, but this is cause for a call for change. The only way to make it easier is to start one step at a time. Foundries must contribute to the development of this technology if they wish to make integration more cost and time effective with an emphasis in this technology functioning in foundry environments.

Moving forward, the AFS Industry 4.0 Committee will use the results of this survey to focus resources to support the needs and wants of industry. Further evaluation of individual facilities will aid in the benchmarking process. One clear take-away from this survey is the need for education of Industry 4.0. One of the supporting events that has stemmed from the committee is the *AFS Foundry Industry 4.0 Conference* (July 30-31, 2024).[5] Conference attendees can learn how data-driven manufacturing, automation, and workforce training can future-proof their operations. Metalcasters can network with industry experts and create an action plan tailored to their unique goals. Conference subject matter is chosen through feedback such as this survey. Further support may include classes, workshops, and tours.

ACKNOWLEDGMENTS

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