Data Analytics Short Courses for Reskilling and Upskilling Indiana's Manufacturing Workforce

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Abstract

The power of ML and AI has not been fully realized in the manufacturing sector. One of the major challenges is that the small and medium manufacturers, which account for 98% of the industry, lack the dedicated data analytic workforce. In Indiana, to address this need, partnerships have been established between industry and academia through Wabash Heartland Innovation Network (WHIN) at Purdue University. In collaboration with Ivy Tech Community College, a series of workshops were developed to introduce data analytics, the internet of things, and basic machine learning concepts to local small and large manufacturing companies. This study will describe the first of three short courses geared toward industry workers and professionals. The first short course was on the topic of energy savings and data analytics for Variable Frequency Drives (VFDs). The attendees consisted of 44 participants from 17 manufacturing companies. A final evaluation of the course reports on participants' levels of satisfaction with the course, the major learnings and takeaways, and their institutional support. The evaluation results indicate that the course was a good introduction to VFDs and the large number of applications where VFD data can be used for energy savings, diagnostics, and operations. However, workshop participants wanted more hands-on opportunities to see how the VFD data can be extracted for new motors and many legacy equipment still in use and how various settings can be adjusted.

1. Introduction

Data analytics and Artificial Intelligence (AI) have transformed many industries in the last decade [1]. In tandem, a skilled workforce needs to understand how to gather/access data to extract trends and optimize operations, and how label the key events, and develop training data sets that can be used by machine learning (ML) experts for advanced analytics. The power of ML and AI has not been fully realized in the manufacturing sector [2]. One of the major challenges is that the small and medium manufacturers, which account for 98% of the industry, lack the dedicated data analytic workforce. This is combined with aging workers and significant challenges in hiring factory floor workers [3]. To address this need, partnerships have been established between industry and academia through Wabash Heartland Innovation Network (WHIN) at Purdue University. In collaboration with Ivy Tech Community College, a series of workshops were developed to introduce data analytics, the internet of things, and basic machine learning concepts to local small and large manufacturing companies. This study will describe the first of three short courses geared toward industry workers and professionals.

2. Training Design

The first short course is on the topic of energy savings and data analytics for Variable Frequency Drives (VFDs). The main goal of this workshop was to introduce electric motor data and VFDs for motor control to industry partners. Motors are a major source of energy consumption in manufacturing and other industries. In the right applications, VFDs can reduce energy usage with relatively short returns on investments. Using VFD or utilizing SMART motor overload devices, it is also possible to gather data for motor diagnostics, predictive maintenance, and process monitoring.

The course was organized into five main sections and three major topics. The course first introduced VF drives and foundational concepts. The course also addressed aspects of capabilities and their uses in the context of manufacturing. The second topic revolved around a review of energy savings applications and the return on investment. It was emphasized that centrifugal fans and pumps are "variable torque" loads. These loads follow what is known as the Affinity Laws: (1) flow is proportional to the shaft speed, (2) pressure is proportional to the $(\text{shaft speed})^2$, and (3) power is proportional to the $(\text{shaft speed})^3$. This means that a reduction in motor speed by 80% can reduce energy consumption by 51%.

Finally, the third topic highlighted proper VFD application and installation considerations. It was shown that in addition to real-time voltage, current, energy and power, VFD data (% thermal capacity utilization, trip/warning histories, and time to reset) can be useful for diagnostics and other data (time to trip, number of starts and operational hours) can be useful for monitoring operations. Once the three foundational topics were introduced, the course focused on the application of those concepts. Participants had an opportunity to discuss how data available through VFDs (refer to Figure 1) and other intelligent motor controls can help with IIoT efforts, such as process improvements and reliability, among other considerations. The course addressed practical considerations such as how to get data from the motors. Specifically, it covered aspects of data collection architectures, data for quality and process optimization, and equipment and process diagnostics.

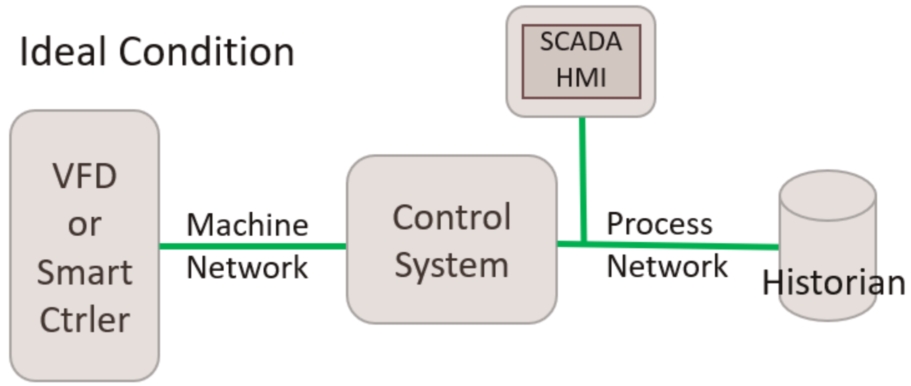
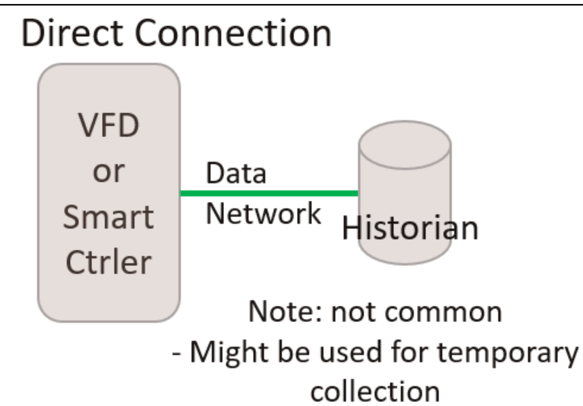
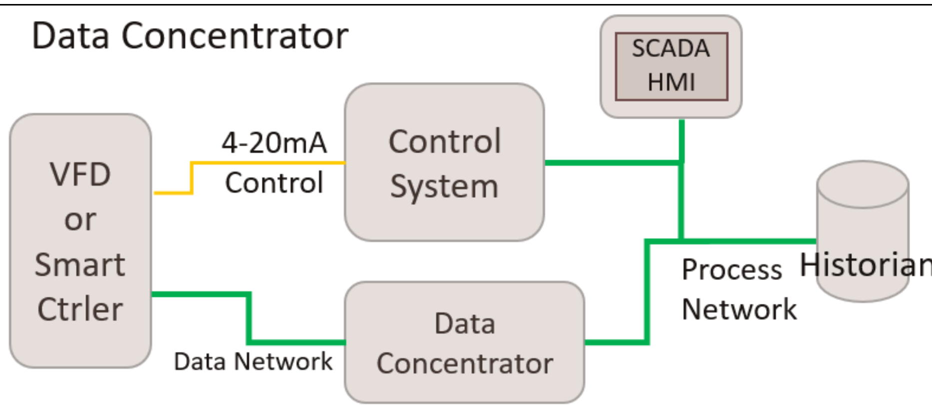
Ideal Condition	
Direct Connection	
Data Connector	

Figure 1. Different ways to get the data from a VFD installation.

Two examples of process data monitoring were described. The batch tank agitator stirs the contents as raw materials are added. As the product nears its final stage, viscosity changes - requiring the agitator to work harder to stir the material. The agitator motor load (current or power) can be monitored as a surrogate for product viscosity to study trends over time and modify the process to run to target agitator load instead of time, ensuring quality and potentially improving productivity. In the second example, the rubber mixer achieves correct properties as a function of the amount of work put into the rubber. As mixer blades wear, less work is done per revolution of the blades. Monitoring overall power and cycle time, one can study the mechanical work on the rubber and also have some indication of the blade condition.

The course concluded with a broader discussion and a question-and-answer session on specific drive applications. After the main lecture and questions and answers, a live demonstration was prepared using a VFD controller and a hair dryer. It was shown how the current and voltage of the hair dryer can be monitored at low and high speeds. Also, by setting appropriate limits, the impact of the overload protection circuit was demonstrated. The user interface for the VFD controller was through a laptop and command text output. Two dozen workshop participants stayed to see the live demonstration.

Although not covered in detail as part of this study, here we provide a brief introduction to the second and third courses. The second course is on the topic of recording and managing data from factory workers' observations. A key requirement for some machine learning applications is the training data set and labeling of key events to complement automatically recorded machine data. In this workshop which was offered in late Fall 2022, AirTable was introduced as a method to reduce paperwork and help capture key events and observations. Examples from electric motor maintenance and computer numerical control (CNC) machining were provided. The third short course was on the topic of industrial internet of things (IIoT) sensors. The course objective is to introduce IIoT device installation, access the data (e.g., power consumption, vibration, temperature), and use dashboards and alarms to monitor the operations. This workshop will be introduced in Spring 2023. Examples of the applications of machine learning to manufacturing include anomaly detection to send alarms to the operators or classification algorithms which can be used to develop a dashboard to monitor a tool or the factory floor operation [4], [5].

3. Course Evaluation Framework

To provide formative feedback on the impact of the three short courses for industry on data in manufacturing, we used an adapted framework of the Kirkpatrick Training Evaluation Model [6], combining elements of Guskey's Evaluation Model of faculty development [7]. Kirkpatrick's and Guskey's models have the first two levels (Level 1 and Level 2) in common, namely, assess of participant's reactions and learning. The third level (Level 3) focuses on organizational support for promoting change, accounting for contextual effects. The fourth and fifth levels of the model (Level 4 and Level 5) focus on the use of the new knowledge and skills as applied in practice and the overall impact on the organization. Please see Figure 2 to see how these levels of evaluation are organized.

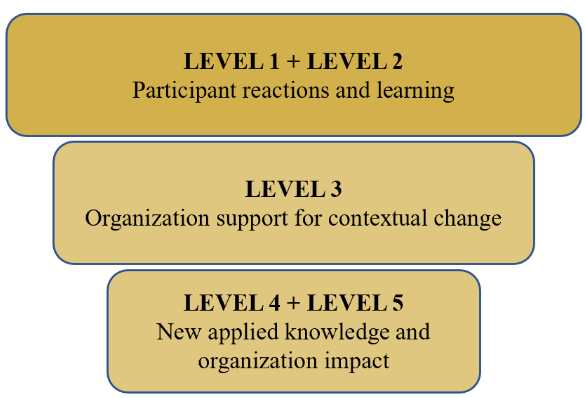


Figure 2. Adapted evaluation framework from [6] [7] models.

This study reports on participants' perceptions regarding Levels 1, 2, and 3 of our evaluation model. Levels 1 and 3 were assessed immediately after the workshop through a survey, and level 2 required applying a form of assessment immediately after the workshop (i.e., performance task). In our future work, we will assess Levels 4 and 5 annually, starting a year after the implementation of the short courses, using objective metrics and interviews with managers. This assessment strategy will start over for each cohort of new participants entering the professional development program.

4. Results

The course had an attendance of 44 participants from 17 manufacturing companies, of which 15 of those are small and medium enterprises (SMEs), and two large companies. Of the total participants, 29% were managers, 25% were engineers, and 46% were maintenance technicians. The response rate was 92.3%. All participants were male, with 4% being Black or African American and 96% White. Participants were asked about their level of expertise. 42% of the participants considered themselves knowledgeable, 46% considered themselves novices, and 12% did not answer this question. No participants considered themselves experts.

Participants were asked about their goals for attending this course. All participants responded that their goal was to gain an understanding of VFD along with the benefits and applications of this technology. One participant responded that their goal was to "stay current with changing needs," and another participant was more specific, responding that their goal was "to understand what and how to extract data and diagnostics from VFDs."

4.1 Level of satisfaction – Level 1

Participants ranked their level of satisfaction with the course activities, the facilitator's performance, the setting the workshop offered, and the level at the workshop fulfilled their goals and expectations. Table 1 summarizes the rankings for each of the questions. Overall, participants expressed that the activities mostly or completely fulfilled their goals (mean=4.47), that the facilitator was prepared and able to engage participants (mean=4.88), the setting of the workshop was adequate (mean=4.79), and that overall, the workshop fulfilled their goals and expectations (mean=4.43).

Table 1. Summary regarding the level of satisfaction with the course.

	Not at All	Very Little	Somewhat	Mostly	Completely
The activities of this workshop					
• Had goals clear to me			8%	50%	42%
• seemed properly planned and executed				20%	80%
• were relevant to me			12%	42%	46%
• gave me ideas applicable to my work			12%	33%	45%
The facilitator of this workshop					
• Was prepared and organized				4%	96%
• Used technology appropriately				12%	88%
• Was able to engage participants				33%	67%
The setting of this workshop offered					
• Comfortable facilities				16%	84%
• A working and learning atmosphere				25%	75%
• A suitable environment for teamwork			8%	16%	76%
• Access to coffee, water, and snacks				8%	92%
This workshop fulfilled my goals and expectations			12%	42%	46%

4.2 Learnings, takeaways, and applications – Level 2

Participants were asked to share the main lessons learned and takeaways from the course. In addition, participants were also asked to name one possible application of the concepts and skills learned in their current job responsibilities. The most common response to the question related to the key concepts and skills learned was an understanding of how a VFD works, its capabilities, and its potential for energy savings. Other responses focused on the specific process of understanding data collection processes. For instance, a participant responded, "What data can be pulled, when it is useful to pull data, and what are the uses for data output."

Participants were also asked to name job responsibilities that they thought could be improved by implementing skills learned in this course. The responses ranged from broad applications such as preventive maintenance, predictive maintenance, monitoring downtime, process savings potential, downtime control, voltage usage, and troubleshooting to more specific applications such as using data collection on chillers, compressors, and injection molders and monitoring of fluid return/supply pumps, fan bearing/blade conditions, noise on a piece of equipment, among others.

Participants were also asked to rank the different components of the course in terms of their relevance and usefulness. Overall rankings were in the mostly and completely useful categories, as shown in Table 2.

Table 2. Summary regarding the clarity and usefulness of the delivered topics.

	Not at All	Very Little	Somewhat	Mostly	Completely
• Overview of VFD principles and applications			4%	33%	63%
• The potential of VFDs for energy saving				33%	67%
• How to get data from electric motors			4%	42%	50%
• Use of motor data for motor diagnostics				38%	62%
• Use of motor data for process monitoring				38%	62%
• Live demonstrations during the workshop		12%	17%	25%	38%

4.3 Resources and support – Level 3

Participants were also asked if they had the resources available to them for further exploring, implementing, and using the skills they learned in the course. All participants responded to this question positively except for two of them, who mentioned they did not have the resources at the time. Participants were also asked about how Purdue could continue to support their work. Responses included offering more individualized workshops complemented with site visits. Assisting in setting up the technology, helping collect data, and training in analyzing data. Also, by offering consultations as needed. Finally, participants were asked to offer suggestions to improve future offerings of the course. Most of the respondents suggested having more hands-on activities and giving opportunities to work directly on the devices.

5. Conclusion

Based on the feedback, the course was a good introduction to VFDs and the large number of applications where VFD data can be used for energy savings, diagnostics, and operations. However, workshop participants wanted more hands-on opportunities to see how the VFD data can be extracted both for new motors as well as many legacy equipments still in use and how various settings can be adjusted. Based on this feedback, we are designing a follow-up workshop where a VFD controller (or SMART overload) is installed on a DC motor as well as commercial IIoT sensors, and a user interface is developed so that workshop participants could each do some exercises to access the motor data, plot them and study the trends. We are also working with manufacturing partners to show real examples of the use of VFD data for process monitoring and other diagnostic applications. We don’t expect factory workers to do data analytics and machine learning. However, they need to understand what machine learning can do so that they acquire the necessary labeled data sets that can be used for the training of advanced algorithms by academic collaborators.

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