A Preliminary Assessment of Industry 4.0 and Digitized Manufacturing in the North American Woodworking Industry

Matthew Bumgardner
Urs Buehlmann

Abstract

Industry 4.0, a term referring to the digitization of manufacturing, enhanced automation, and data-driven production systems, promises to bring rapid change to the secondary woodworking industry. Manufacturers in this sector, many being small in size and scale, may be challenged to remain competitive without understanding how Industry 4.0 principles might affect their operations. A study conducted with subscribers to a major secondary wood industry trade journal found that few North American woodworking companies were familiar with the term ''Industry 4.0.'' However, that did not mean they were not making decisions about, investing in, and implementing digitization–computerization (digit–comp) in their manufacturing operations. Well over half of study respondents indicated that their firms had made a significant investment in digit–comp over the past 3 years. Several respondents stated that software and technology integration was the most unexpected problem encountered, and that skilled labor was difficult to find. A variety of training types were sought by firms that had made significant Industry 4.0-related investments, especially training related to machine operation. Although a plurality of respondents from both small and large firms indicated that increased digit–comp would not change their number of employees, small firms were more likely to say more employees would be needed and large firms were more likely to perceive a decrease in employees. Perhaps the greatest challenge to successful implementation of Industry 4.0 will be the lack of a strategic plan—just 19 percent of small firms indicated having a vision of how digitization might affect their business.

Industry 4.0, a term coined by Kagermann et al. (2011), is used to describe the ongoing digitization and rapid technological advancement in industry and society. In a manufacturing context, Industry 4.0 refers broadly to smart manufacturing systems and the interconnectedness of data. Industry 4.0 has been referred to as the fourth industrial revolution (Vogel-Heuser and Hess 2016), after the steam machine in the 1780s (first industrial revolution), the linear assembly line after the turn of the 20th century (second industrial revolution), and the introduction of programmable logic controllers in the 1960s (third industrial revolution; Schwab 2016).

At its core, Industry 4.0 is centered around five digital technologies (i.e., additive manufacturing, augmented reality, cloud computing, cyber security, and big data analytics [Kagermann et al. 2013, Gerbert et al. 2015, PwC 2016]). The vision calls for highly customized products manufactured in industrial production settings using smart shops that are adaptable and resource-efficient. Industry 4.0 is poised to drive a revolution in manufacturing based on advances in big data and analytics, autonomous robots, simulation, system integration, the Internet of Things (IoT), the cloud, additive manufacturing, and augmented reality, to name a few aspects (Foresight 2013). For Industry 4.0 to become reality, cyber–physical, smart human–machine systems must be matched with intelligent work pieces that are connected via IoT (Kögel 2016). This networked production requires vertical and horizontal integration (from the start of the customer contact to final delivery and installation of the products), a complete digitization of all the information created and exchanged throughout the value chain, an intelligent work piece (e.g., the piece is uniquely

The authors are, respectively, Research Forest Products Technologist, Northern Research Sta., USDA Forest Serv., Delaware, Ohio (matthew.bumgardner@usda.gov [corresponding author]); and Professor, Dept. of Sustainable Biomaterials, Virginia Tech, Blacksburg, Virginia (buehlmann@gmail.com). This paper was received for publication in October 2021. Article no. FPJ-D-21-00064R1

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identifiable and its data are always callable), and intelligent machines throughout the process (e.g., every machine is interacting with the control center and with equipment in the value chain).

Digitization is bringing vast changes to manufacturing practices everywhere (Foresight 2013, Schwab 2016), including to the US wood industries (Hardwood Market Report 2016). Industry 4.0 holds opportunity for the future competitiveness of the US woodworking industry because it will help domestic manufacturers better meet the needs of customers, who increasingly are focused on expectations for customized product choices and short lead times to delivery (Schwab 2016). However, there are indications that the secondary wood products industry might not be ready for large-scale adoption of Industry 4.0. In Malaysia, for example, relatively low labor costs were found to dissuade implementation of Industry 4.0 in the furniture industry (Ratnasingam et al. 2019).

The adoption of Industry 4.0 principles and practices will challenge the US woodworking industry as well, given the small size and scale of many firms. For example, while 58.1 percent of all US manufacturing firms (North American Industry Classification System [NAICS] codes 31 to 33) had fewer than 10 employees in 2019, 73.0 percent of the wood kitchen cabinet industry (NAICS 337110) had fewer than 10 employees (Bureau of Labor Statistics 2022a). The resource-based view of the firm (RBV) states that larger firms possess more internal capabilities and resources than smaller firms, giving them a competitive advantage (Hoopes et al. 2003). In particular, RBV studies have suggested that investment capital and the skills needed to start up and exploit modern technology are resources associated with larger sawmills (Lahtinen et al. 2008). Other studies have shown that smaller woodworking firms are less likely than larger firms to engage in information-seeking activities, which likely is a function of time constraints and limited travel resources (Buehlmann et al. 2013). A study of the primary and secondary Slovenian wood industry found that medium- to large-sized firms had adopted digitized manufacturing technology to a greater extent than smaller firms, largely because of the high investment and maintenance costs (Kropivsek and Groselj 2020).

For suppliers, researchers, and outreach specialists to better serve the secondary woodworking industry in the 21st century, more information is needed regarding the impacts of Industry 4.0. The objective of this study was to discern the perceptions and experiences of secondary woodworking manufacturers concerning Industry 4.0, or more broadly the digitization–computerization of their manufacturing operations. For the remainder of this paper, digitization–computerization will be referred to as ''digit–comp.''

Methods

The target population for the study was secondary wood products manufacturers in North America. The sampling frame was subscribers of *Woodworking Network/FDMC*. A total of 139 usable responses were received after three email invitations were sent by *Woodworking Network/FDMC* to complete a 27-question survey instrument online in November and December of 2019. A response rate was difficult to calculate given that the invitations were sent out to 44,000 email addresses that included several nontarget firm types (primary processors, raw material suppliers, educators, machinery manufacturers, machinery suppliers, hardware manufacturers, installers, etc.). Those responding firms that were in nontarget sectors were excluded from analysis. Draft versions of the survey instrument were reviewed by a wood industry consultant familiar with Industry 4.0 and a member of academia (wood products faculty) before the instrument was finalized. Review comments focused on refining the technical aspects of some questions and enhancing question clarity and structure. The instrument included questions with categorical responses (check all that apply; multiple choice), rating responses (scales), and fill-in-the-blank (qualitative) responses.

Sample description

A plurality of responding firms (45.3%) were manufacturers of kitchen or bath cabinets, while 13 responses were received from office–hospitality–contract furniture manufacturers (9.4%) and 12 responses were received from household furniture manufacturers (8.6%). A sizeable percentage of responses also was received by architectural fixture firms (7.2%). Several other respondents that marked ''other'' described their main product such that it could be categorized as architectural fixtures; including these, 10.8 percent of respondents were categorized as architectural fixture firms. Smaller percentages of firms were primarily manufacturers of molding–flooring, windows or doors, store fixtures, closets, dimension or component products, and products classified as other.

Large majorities of respondents indicated that their companies used composite products (85.5%), plywood (82.0%), and hardwood lumber (81.2%) to manufacture products. Fewer firms indicated that softwood lumber (54.7%), wood dimension products (27.4%), and wood components (22.2%) were used. The most common distribution channels for respondents' companies were direct to end-users (65.0%), factory showrooms (26.5%), and the internet (21.4%). Fewer companies used dealers, independent and big box retailers, or factory-owned stores.

Most respondents (67.6%) indicated that they held positions within their firms in corporate or operating management. When including the respondents indicating that they were the owners of their firms, this percentage increased to 74.8 percent. Another 8.6 percent were production managers. A limitation of this study stems from a single information source representing the views and experiences of the entire company, but most respondents were at least in positions of leadership within their respective firms.

Nearly 80 percent of respondents represented companies with fewer than 50 employees. A majority of firms (54.7%) had fewer than 20 employees. Most firms had sales of $\leq$\$10 million (87.2%), with a majority of firms realizing sales of US\$1 to \$10 million in 2018 (59.0%). Most firms indicated they operated at a medium-high to high price-point (71.8%) and that $\geq$60 percent of their product mix was completely made-to-order production (83.8%). When asked in what US state or Canadian province the majority of their manufacturing was located, respondents listed 38 states and 4 provinces. Pennsylvania, California, Ohio, Texas, Massachusetts, Minnesota, and Michigan each accounted for $\geq$5 responses and 27 respondents cited their principal manufacturing operations as located in Canada (17 in Ontario).

Assessment of nonresponse bias

A sizable majority of respondents (64.2%) indicated that they had made a significant digit–comp investment within the past 3 years, suggesting that responses received might have leaned toward larger firms with greater interest or experience in such investments. Likewise, 55.6 percent of cabinet manufacturers in the study sample had fewer than 10 employees while 73.0 percent of firms in the overall US wood kitchen cabinet industry (NAICS 337110) had fewer than 10 employees in 2019 (Bureau of Labor Statistics 2022a). In terms of product type, secondary data available for the woodworking industries covered in this study (including 12 NAICS codes covering the wood, upholstered, and commercial furniture, flooring, kitchen cabinet, and millwork industries as described in Luppold and Bumgardner 2008) showed that kitchen cabinets accounted for 42.4 percent of the number of establishments in 2019 (Bureau of Labor Statistics 2022b). This compares favorably with the study sample, where 45.3 percent of respondents were cabinet manufacturers.

Another method for detecting nonresponse bias is to compare early and late respondents because some studies indicate that later survey respondents resemble nonrespondents (Lahaut et al. 2003, Baruch and Holtom 2008). A comparison of early respondents (to the first email, $n = 57$) and late respondents (to the final email, $n = 33$) using chi-square tests of 2 by 2 tables found no statistical differences based on firm size (as defined below, $P = 0.86$), whether a significant investment in digit–comp had been made in the past 3 years ($P = 0.81$), or whether the company had a strategic vision of how digitization might affect business in the mid- to long-term ($P = 0.21$), which suggests nonresponse bias was not a substantial factor in this study. Overall, limitations of the study stem from the sample coming from a single source, a limited sample size, and some indication that larger firms were more likely to respond.

Data analysis

Study results are presented in aggregate unless otherwise noted. Comparisons between ''small'' firms (defined as <20 employees) and ''large'' firms (defined as ≥20 employees) also were made because they might have different perspectives and experiences (Buehlmann et al. 2013). In addition, those respondents reporting that their firms had made significant investments in digit–comp of manufacturing operations in the past 3 years were asked additional questions about those experiences, because others have noted that implementing automation technology can lead to new training and maintenance needs for secondary wood manufacturers (Lamb 1994). An alpha level (α) of 0.10 was used for developing confidence intervals on the aggregate results, chi-square tests of independence, *t* tests (means), and *z* tests (proportions). When multiple tests (i.e., *t* tests or *z* tests) were conducted for a given question, Bonferroni's correction (α/number of tests) was applied given that large numbers of tests were conducted without preplanned hypotheses (Armstrong 2014). Statistical analyses were carried out using SAS Enterprise Guide version 7.1 and Social Science Statistics (2020).

Results and Discussion

Respondents were asked their level of familiarity with the term ''Industry 4.0.'' On a scale ranging from 0 (*Not at all*) to 10 (*Very much*), the average score was 3.7 and 52.2 percent of respondents provided a rating of ''3'' or lower. Thus, it seemed that overall familiarity by the industry was somewhat low. However, when asked how computerized their respective manufacturing facilities were at this time, respondents averaged a score of 4.6 on a scale ranging from 0 (*No computers are being used*) to 10 (*Humans only supervise a fully automated, computerized facility*), which was near the scale midpoint.

More specifically, respondents were asked whether their company had increased the use of digit–comp in several manufacturing-related applications over the past 3 years. The results are shown in Table 1. Designing products, machining, and communicating with customers to help them visualize product features were the three most commonly selected applications. Product engineering and optimization of raw material processing also were mentioned relatively frequently. Facilitating robotics and finishing were the least used applications. Interestingly, only 13 percent of respondents indicated that they had not increased the use of digit–comp in any manufacturing-related application. There were notable differences between small and large firms among the applications, with product engineering ($P < 0.001$), inventory tracking ($P < 0.001$), manufacturing data collection ($P < 0.001$), material handling ($P = 0.002$), and shipping or distribution ($P < 0.001$) all being applied more frequently by large firms based on *z* tests of the proportions. In addition, assembly ($P = 0.008$) was borderline significant based on the Bonferroni correction for alpha ($\alpha = 0.007$).

Respondents also were asked qualitatively to indicate any other applications where digit–comp had been added. Several respondents mentioned CNC/CAD-type applications; the other theme mentioned by several respondents

Table 1.—Manufacturing-related applications where responding companies increased the use of digitization–computerization over the past 3 years (respondents could check all that applied).

Manufacturing applications	Companies increasing use (%)	Lower 90% confidence limit (%)	Upper 90% confidence limit (%)
Designing products	67.6	61.1	74.1
Machining	65.5	58.9	72.1
Helping customers visualize product features	57.6	50.7	64.5
Product engineering	46.8	39.8	53.8
Optimization of raw material processing	36.7	30.0	43.4
Inventory tracking	26.6	20.4	32.8
Enable more customization of product attributes	24.5	18.5	30.5
Increase data collection from mfg. processes	24.5	18.5	30.5
Assembly	21.6	15.9	27.3
Material handling	20.1	14.5	25.7
Shipping and distribution	15.8	10.7	20.9
Finishing	14.4	9.5	19.3
To facilitate robotics	6.5	3.1	9.9
We have not increased use	13.0	8.3	17.7

was Enterprise Resource Planning or related areas such as employee database access and paperless shop floors.

Given that only 13 percent of respondents had not increased digit–comp in any manufacturing-related applications within the past 3 years, it was not surprising that respondents rated most potential barriers to increasing digit–comp to be relatively low (Table 2). Finding skilled labor and the needed capital for the investment were rated as the greatest barriers. The relatively low ratings for ''potential benefits are unclear'' and ''proven technology does not exist'' suggest that most firms generally recognize that tangible benefits are possible with digit–comp investments. There was a significant difference between small and large firms regarding ''potential benefits are unclear'' ($P = 0.008$; small firms rated higher), but again this barrier was rated as relatively unimportant by both groups. Training needs of employees ($P = 0.011$) and ''expected return on investment not sufficient'' ($P = 0.010$) were borderline significant based on the Bonferroni correction for alpha ($\alpha = 0.009$), and in both cases, small firms rated these barriers higher.

Even though most barriers to increasing digit–comp were rated somewhat low, only 33.6 percent of respondents indicated that they had a strategic vision of how digitization might affect their company in the mid- to long-term (Fig. 1). A plurality of respondents (40.9%) said their firm did not have a strategic vision regarding digit–comp and 25.6 percent were uncertain. Importantly, just 18.7 percent of small firms indicated that they had a strategic vision, while 51.6 percent of large firms reported having such a vision. Overall, small firms differed from large firms on the strategy variable based on a chi-square test of the 2 by 3 table ($P < 0.01$).

Respondents were asked their perceptions of the potential impacts of increased digit–comp on their firm's employment. As shown in Figure 2, a plurality of respondents (39.9%) indicated there would be no change in their number of employees, and another 27.5 percent of respondents were uncertain of the potential impact on employment. A similar number of respondents indicated perceived employment increases (16.7%) or decreases (15.9%) attributable to increased digit–comp. When looking at responses by firm size, the chi-square test of the 2 by 4 table comparing small and large firms was significant ($P = 0.03$). Interestingly, small firms were more likely to say there would be a gain in employment (19.7%) versus a loss in employment (7.9%), while large firms were less likely to say there would be a gain in employment (12.9%) versus a decrease (25.8%). This might suggest that small firms see digit–comp as an investment that would require more technical skills than they currently have on staff, while large firms see potential efficiencies. However, in both groups a plurality indicated there would be no change in employment (40.8% for small firms and 38.7% for large firms).

Experiences of companies that invested in digitization–computerization

Respondents were asked whether their companies had ''made a significant investment in the digitization–computerization of your manufacturing operations in the past three years.'' Over 64 percent ($n = 88$) indicated that they had made such an investment. These respondents then answered additional questions specific to their experiences, including potential benefits, unexpected problems, training sought, and maintenance needs. These results are described below.

Table 2.—Scale means for barriers to increasing digitization–computerization in respondents' manufacturing facilities (scale ranged from 1 = strongly disagree *to 5 =* strongly agree*).*

Barriers	Mean	Lower 90% confidence limit	Upper 90% confidence limit
Skilled labor difficult to find	3.7	3.5	3.9
Finding the capital needed for the investment	3.3	3.1	3.5
Training needs of employees	2.9	2.7	3.1
Expected return on investment not sufficient	2.8	2.6	3.0
Getting 'buy-in' from employees	2.6	2.4	2.8
Maintaining new technology too expensive	2.6	2.4	2.8
In-house processes too complex for systems	2.5	2.3	2.7
Too disruptive to existing operations	2.4	2.2	2.6
Necessary technical information not available	2.4	2.2	2.6
Potential benefits are unclear	2.3	2.1	2.5
Proven technology does not exist	2.2	2.0	2.4

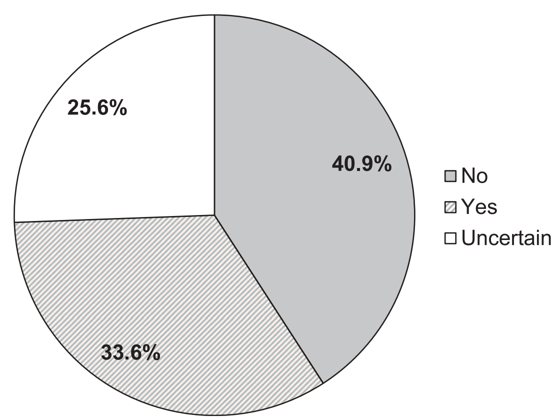

Figure 1.—Response breakdown (by percent) to the question, "Does your company have a strategic vision of how digitization might affect your business in the mid- to long-term?"

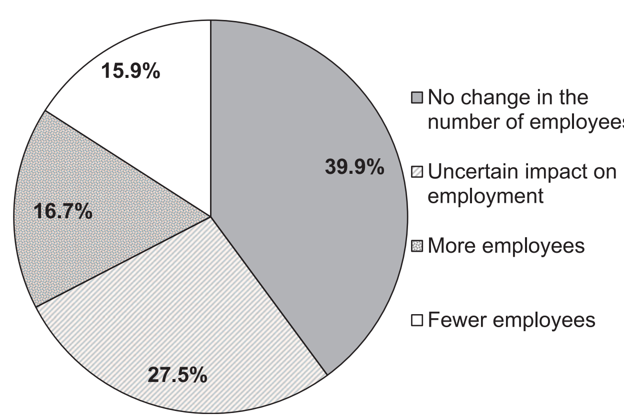

Figure 2.—Response breakdown (by percent) to whether increased digitization–computerization of respondents' manufacturing facilities would lead to increased, decreased, or unchanged employment.

The subsample for this analysis consisted of 46.6 percent small firms and 53.4 percent large firms, with all product types represented.

As shown in Table 3, the most important potential benefits to the decision to digitize–computerize operations were improved productivity, improved product quality, improved consistency within manufacturing processes, and the enablement of increased customization of products. The least important potential benefits were enabling leaner manufacturing, improved raw material utilization, enabling the collection of real-time manufacturing data, and helping address labor shortages. There was a notable difference between small and large firms regarding collection of real-time manufacturing data, with large firms rating this benefit a 4.0 and small firms rating it a 2.8 on the 5-point scale, which was a significant difference ($P < 0.001$) based on the Bonferroni correction for alpha ($\alpha = 0.009$).

When asked separately to qualitatively describe the greatest benefit realized by the investment, issues related to productivity, product and process consistency, and product quality emerged as important themes. These benefits were similar to the quantitative results shown in Table 3. However, based on the qualitative question (compared with Table 3), improved information flow through the company and speed (manufacturing, speed to market, etc.) surfaced as important benefits. One respondent indicated that the information available helped them know their own company better.

Respondents that had made a significant investment also were asked to qualitatively describe the most unexpected problem encountered. Issues related to software and technology integration across platforms were mentioned most frequently, followed by managing the ''learning curve'' or similar answers. Several respondents also responded with ''none'' or similar answers. The technology integration issue was especially interesting given that related barriers were rated as somewhat unimportant in Table 2 when all respondents (those making an investment and those not making an investment) were asked about barriers to increasing digit–comp. Perhaps technology integration issues become more apparent once companies gain experience in implementation. Another interesting item was the availability of skilled labor, which was rated as the most important barrier to increased digit–comp in Table 2 but was mentioned less frequently in the qualitative question by those that had made the investment.

There were other more idiosyncratic answers to the qualitative question regarding unexpected problems that were notable. A few companies indicated that their systems had features that were underutilized, which might mean more training is needed or that systems could be designed to better match specific needs. Other respondents said that the investment in digit–comp had led to the magnification of inefficiencies and imperfections in their organizations, which were viewed as problems but actually might be opportunities for improvement. Another respondent mentioned that the resulting lack of redundancy hurts when a machine goes down.

Respondents that had made a significant investment were then asked to indicate in what areas formal training was sought for their manufacturing employees to implement digit–comp in their facilities. By a large margin, machine operation was the most common form of training sought, with several other training areas being mentioned by a quarter to a third of respondents (Table 4). Only 20.0 percent of respondents indicated that no formal training was sought, suggesting that training is an important component of digit—comp implementation. There was a notable difference between small firms and large firms regarding advanced programming, with 45.7 percent of large firms and 20.0 percent of small firms indicating formal training was sought related to advanced programming, a difference that was borderline significant ($P = 0.017$) based on the Bonferroni correction for alpha ($\alpha = 0.013$).

Another topic addressed was maintenance and repair of computerized manufacturing equipment. Perceptions of respondents from companies that had made such investments were queried. As shown in Table 5, for both *general maintenance* and *repair,* a majority of respondents see a combination of in-house expertise and outsourcing as the optimal way to receive service. However, differences in the 2 by 3 table were significant based on a chi-square test ($P = 0.024$), with respondents indicating they would prefer in-house service for general maintenance (30.7%) more than repair (14.7%).

Table 3.—Scale means for the importance of potential benefits to the decision to digitize–computerize operations (scale ranged from 1 = not important to 5 = very important).

Potential benefits	Mean	Lower 90% confidence limit	Upper 90% confidence limit
Improves productivity	4.6	4.5	4.7
Improves product quality	4.4	4.2	4.6
Improves consistency within mfg. processes	4.4	4.2	4.6
Enables increased customization of products	4.2	4.0	4.4
Improves manufacturing flexibility	4.1	3.9	4.3
Shortens lead times from order to delivery	4.0	3.8	4.2
Improves speed to market	4.0	3.8	4.2
Enables leaner manufacturing	3.9	3.7	4.1
Improves raw material utilization	3.8	3.6	4.0
Ability to collect real-time manufacturing data	3.5	3.3	3.7
Helps address labor shortage issues	3.5	3.2	3.8

Table 4.—Areas where formal training was sought for manufacturing employees to implement digitization–computerization in respondents' facilities (respondents could check all that applied).

Training areas	Companies seeking (%)	Lower 90% confidence limit (%)	Upper 90% confidence limit (%)
Machine operation	62.7	53.5	71.9
Basic computing (file management, etc.)	33.3	24.3	42.3
Advanced programming	32.0	23.1	40.9
Basic programming	29.3	20.7	37.9
Equipment maintenance and repair	29.3	20.7	37.9
Basic software use (spreadsheets, etc.)	26.7	18.3	35.1
Lean manufacturing principles	26.7	18.3	35.1
No formal training was sought	20.0	12.4	27.6

Table 5.—Based on respondents' experiences to date, percentages indicating the optimal ways to provide general maintenance and repair services for computerized manufacturing equipment. Overall differences in the 2 by 3 table were significant based on a chi-square test (P = 0.024).

	In-house expertise	Outsourcing	A combination
General maintenance	30.7	2.7	66.7
Repair	14.7	9.3	76.0

Lastly, respondents that had made a significant investment in digit–comp in the past 3 years were asked to rate how successful their efforts had been. On a scale ranging from 1 (*Very Unsuccessful*) to 10 (*Very Successful*), the average response was 6.7, with a minimum rating of ''2'' and a maximum rating of ''10.'' Over 65 percent of respondents indicated a ''7'' or higher on the scale, and nearly half (49.3%) indicated either a ''7'' or an ''8.'' Small firms and large firms had similar averages on the scale (6.7 and 6.8, respectively) even though a higher percentage of large firms (75.8%) indicated they had made a significant investment in digit–comp than small firms (54.7%).

Summary and Conclusions

Familiarity with the term ''Industry 4.0'' was found to be somewhat low. However, this does not mean that secondary woodworking companies are not making decisions about, investing in, and implementing digit–comp in their manufacturing operations. Well over half of respondents (64.2%) indicated that their firms had made a significant investment in their manufacturing operations in such endeavors over the past 3 years. In fact, most potential barriers to digit–comp investments investigated in the study were rated as relatively unimportant; only skilled labor requirements and capital were rated as somewhat important. Similar barriers were found to be important to Industry 4.0 implementation in the wood industry (Kropivsek and Groselj 2020). However, several respondents with experience in digit–comp investments stated that software and technology integration was the most unexpected problem encountered.

Digit–comp investments were not seen as a solution to labor shortages so much as a means to improve productivity, product quality, and the speed or consistency of manufacturing processes. Although interest in collecting real-time manufacturing data was not rated as an important potential benefit overall, several respondents that had made a significant investment in digit–comp mentioned in their qualitative comments improved information flow as the greatest benefit realized from the investment. Broadly speaking, most respondents did not perceive that there would be a major impact on employment in their respective companies from increased digit–comp. However, small firms were more likely to say they would need additional employees while large firms were more likely to say they would need fewer employees. Although data collection was conducted prior to major industry disruptions from the COVID-19 pandemic, it would be interesting in future work to determine whether automation is viewed more favorably as a way to address labor supply issues.

Digit–comp investments led to more employee training requirements. Interestingly, the kinds of training that were being sought were diverse in nature, with about 30 percent each of responding companies seeking training centered on basic computing and software use, basic or advanced programming, equipment maintenance and repair, and lean manufacturing principles. Only machine operation was indicated by a majority of respondents (62.7%) as a formal training topic that had been pursued. Thus, training needs appear unique to individual firms and their respective capabilities and investments. Respondents also indicated that at least some outsourcing would be needed (vs. in-house expertise) when providing both general maintenance and repair for computerized equipment, which also is a long-term cost consideration for increasing use of such equipment.

There were notable differences between small and large firms. Large firms increased the use of digit–comp more than small firms in nearly every application shown in Table 1, and several of these differences were statistically significant. This finding seems consistent with other studies where smaller woodworking companies planned fewer investments for their operations compared with larger woodworking firms (Buehlmann et al. 2013). Large firms also rated the real-time collection of manufacturing data significantly higher than did small firms as a potential benefit of digit–comp investments, and large firms had sought more training in advanced programming. Taken together, these results are consistent with the RBV view (Hoopes et al. 2003) and suggest that large firms are more likely to have the internal resources needed not only to analyze and ultimately conduct digit–comp investments, but also to operationalize the high-level capabilities of such investments.

Overall, responding firms tended to rate the success of their efforts to digitize–computerize operations as somewhat successful, and this was equally true for both small and large firms (even though more large firms than small had made significant investments). This suggests that an acceptable return on investment is achievable (regardless of firm size) if the necessary capital and employee skills can be obtained to facilitate digit–comp investments. However, just 18.7 percent of small firms indicated that their respective companies had a strategic vision of how digitization might affect their business in the mid- to long term, suggesting few are systematically thinking of the changes Industry 4.0 might bring.

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