Artificial Intelligence in Materials Handling: How Machine Learning Tools Boost Warehouse Safety, Productivity, and Cost-Effectiveness

Introduction

Once only fodder for science-fiction films, artificial intelligence (AI) technologies and tools are now widely accepted and implemented across the globe in all spheres of industry. This journey from novel concept to valued business tool with myriad proven practical applications has occurred only recently and is still rapidly evolving. For the purpose of this paper, the authors use this broad definition of artificial intelligence, offered by Dr. Daniel Merchán of the Massachusetts Institute of Technology's Center for Transportation and Logistics:

> *The ability of machines to perform cognitive functions associated with the human mind, artificial intelligence consists of a set of computational technologies developed to sense, learn, reason, and act appropriately*.

Artificial intelligence has been widely documented in the literature as a way to reduce costs, increase revenue, and enhance asset utilization.[1] Among other subsets of AI, machine learning (ML)—in essence, the ability of machines to use past data to build models capable of making predictions on future data—has proven effective for predictive supply chain modeling. As such, the growing popularity of AI and ML solutions—across all sectors and specifically in supply chain management—is not surprising.

Recent research from global analytics firm RELX shows that overall implementation of AI technologies across the business landscape increased for the third consecutive year. Tracking the ascent of AI, RELX has seen the number of business leaders who report using AI technologies rise to 81%, up from 72% in 2019 and 48% in 2018. The 2020 annual report from global research firm McKinsey, *The State of AI*, finds 50% of respondents' organizations have adopted AI in at least one function. The firm also reports that 71% of companies expect increased investment in AI in the short- to mid-term future (2018).

In the supply chain arena specifically, 76% of respondents to the McKinsey survey in 2019 agreed that supply chain management will benefit significantly from AI adoption. The firm posits that supply chain management/manufacturing is a functional area where AI will have one of the largest impacts, including a potential $1.2 trillion to $2 trillion value (2019). However, overall penetration of AI in the supply chain is still relatively low. Just 12% of supply chain professionals surveyed in 2020 by MHI say they are currently using artificial intelligence in their operations, while 60% expect to be doing so within the next five years. This leaves ample room for supply chain practitioners to explore the potential benefits of AI and embrace the technology as early adopters.

AI's Growing Importance in Research and Practice

Research firm Deloitte states in its 2020 *State of AI in the Enterprise* report that adopters of AI technologies continue to have confidence in the ability of AI to drive value and advantage and that virtually all AI adopters are using AI to improve efficiency, while mature adopters are also harnessing the technologies to boost differentiation.

The drivers for adopting AI in business have been well vetted in the literature. The main draws can be succinctly categorized as follows: the creation of competitive advantage, the launch and improvement of new products, and cost reductions and operational improvements.[2]

The effectiveness of AI in the supply chain has also been researched extensively, with studies noting its proven importance for a wide range of specific logistics-related functions including demand forecasting and optimization, supplier selection, promotion and pricing, and smart manufacturing.[3] It has also been found that supply-chain leaders use AI-powered technologies to make efficient designs to eliminate waste, drive real-time monitoring and error-free production, and facilitate lower process cycle times. Older studies have focused on examples of AI applications including in distributed supply chain planning[4]; design and simulation of supply chain systems[5]; analysis of the complex behavior of supply chains[6]; and negotiation-based collaborative modelling[7]; as well as controlling and monitoring warehouses, food supply chains, and sustainability in supply chains[8]; improving knowledge management and marketing[9]; and enhancing supply chain innovation capabilities[10].

Machine learning-based technologies and tools—which allow machines, systems, and software to adjust without being specifically programmed to do so—have proven especially enticing for supply chain and logistics applications. These technologies' specific proficiency at analyzing trends, detecting anomalies, and deriving predictive insights within massive data sets render them ideal for automating SCM tasks and helping organizations to scale their infrastructure. The actionable insights delivered by ML tools allow for quick problem-solving and continuous improvement which, in turn, helps to drive productivity as well as cost savings.

A January 2019 roundtable discussion at MIT on artificial intelligence and machine learning in supply chain planning outlined several practical uses of machine learning, highlighting its efficacy in real-world supply chain scenarios that included an omnichannel apparel retailer using ML to optimize price markdowns and an ocean freight data company and a 3PL utilizing ML to predict transportation-asset activities and in-transit risks.

Early adopters of AI- and ML-driven data analytics in supply chain management are reporting numerous benefits including the ability to cut inventory by 20% to 30%, increase fill rate by 3% to 7%, generate margin improvements of as much as 1% to 2%, and identify opportunities for saving up to 15% to 20% on transportation costs.[11]

Clearly, optimizing supply chain management through the use of AI and ML technologies is gaining traction and becoming a more prevalent priority for supply chain professionals. The authors think that AI tools could have a transformative impact in warehouse settings by significantly boosting safety, making the use of AI in warehouses a compelling area for further academic study. While the warehouse is a key component within logistics and supply chain management, warehousing research remains an understudied area, accounting for only a fraction of the overall research within this field; and, of the extant warehouse research, attention has largely been placed on warehouse design, performance, and technology use, overlooking the determinants of AI adoption within warehouses.[12] Warehouse safety, specifically, is under-researched: The amount of occupational safety research over the last decades has been extremely low, with less than 1% of the organizational research publications in top journals being related to this subject.[13]

Warehouse Safety Issues—And How AI Can Help

While warehouse operators today are highly focused on safety, evidence exists that warehouses can be dangerous places to work. Common hazards, according to OSHA, include falls as well as collisions between moving vehicles and between vehicles and pedestrians. OSHA cites unsafe use of forklifts, improper stacking of products, failure to use proper personal protective equipment, failure to follow proper lockout/tagout procedures, and inadequate fire-safety provisions as top causes of warehouse accidents. The U.S. Department of Labor singles out forklifts, docks, conveyors, materials storage, and manual lifting and handling as areas/tasks having the highest incidences of accidents.

Forklift accidents are one of the leading areas of concern. Today's modern, multifaceted warehouses are a hive of activity, deploying large fleets of forklifts navigating through hundreds of thousands or even millions of square feet. Despite numerous safety regulations—like mandatory seatbelt use, a ban on using cell phones while in the vehicle, etc.—incidents occur frequently. Data from the National Safety Council (NSC) shows 79 fatal forklift-related injuries and 8,140 non-fatal forklift-related injuries in the United States in 2019. Of those incidents, the three largest categories are "transportation incidents" (49%), "contact with an object or equipment" (33%), and "falls, slips, and trips" (14%).

In addition to worker safety, warehouse safety infractions—and their solutions—hold other concerns as well: Occupational safety measures cost time, compete for managerial attention, and often also cost money.[14]

Equipment damage—to the forklifts themselves as well as to the racks, conveyors, dock doors, and other equipment that forklifts may collide with—plus worker's compensation costs, lost-productivity expenses, and fines and/or legal fees can all add up. Fines from OSHA alone can run from $7,000 for what is considered a minor infraction up to $70,000 for repeated issues.

The National Safety Council puts the direct cost of one injury-causing forklift accident at $38,000 and cites the indirect costs, such as lost work time, as being four times greater—a total of nearly $200,000 in direct and indirect costs per accident.

To help mitigate employee harm and escalating safety costs, forklift manufacturers and third-party solutions providers have paid great attention in recent years to new offerings that can offset operating risks by boosting driver safety. Technological advancements to forklifts have comprised everything from virtual reality simulators for training to on-equipment safety enhancements like telemetry modules, sensors, cameras, RFID warning systems, radar-based speed controls, overload-prevention options, and even geolocation tracking and driver-assistance systems.

These solutions offer various safety and efficiency improvements but also have limitations including cost barriers and training obstacles. When evaluating the effectiveness of magnetic field proximity-sensing technology deployed in an active indoor manufacturing environment, for example, Awolusi, Marks, and Song noted the benefits as the system's ability to alert pedestrian workers and forklift operators when a hazardous proximity situation exists. They cite the following limitations, however: the steep learning curve to transition an entire manufacturing site to the use of the technology and the significant monetary investment to implement the devices.[15]

Greater opportunity exists to combat forklift accidents and boost warehouse safety by using AI and ML technologies that offer a strategic advantage through the continuous improvement approach that machine learning engenders. These tools provide not only important real-time data to help warehouse managers better understand the root causes of safety incidents but also can, through continued use, predict and warn when such incidents are likely to reoccur. The following use case provides context for a real-world application of ML technology in a warehouse setting.

AI in Action in the Warehouse: Case Study

Holman has been in continuous operation since its founding in 1864. The company now operates as Holman Logistics, a third-party logistics firm that provides warehousing, manufacturing support, multi-modal transportation, and omnichannel fulfillment services. Its operations across the country include both multi-client and dedicated locations, ranging from 250,000 sq. ft. to more than 1 million sq. ft. Holman serves a wide range of clients, including Fortune 500 companies, in the CPG, paper products, food and beverage, pet food, electronics, home appliances, heavy equipment, and raw materials sectors.

With safety as one of its main focuses, Holman was seeking a way to reduce the number of accidents experienced in its warehouses. While the firm already enlisted technology, training, and other resources to maintain superior safety performance, driving further improvements was an important goal. In order to reduce the human and financial impacts of safety incidents, the company was eager to better understand the root causes of forklift accidents at its facilities and to determine whether a solution based upon technology could also help prevent future incidents. Senior executives were intrigued by the benefits that artificial intelligence tools were producing in the industry, and the firm initiated a pilot partnership with solutions provider OneTrack.

Based in Chicago, Illinois and Sunnyvale, California, OneTrack is an artificial intelligence technology provider whose computer vision and deep learning solutions aim to help warehouses run safely and efficiently. The OneTrack system works as follows: A lift-mounted 360-degree camera captures images from the forklift, while onboard algorithms and software parse out advanced data from those images in order to "make sense" of what is occurring in the warehouse. The cameras connect to the OneTrack system in the cloud, which offers real-time analytics and workflow tools. Because it is based on machine learning, the solution is able to determine and recognize patterns—and most importantly, anomalies from those patterns—within the captured data and predict when those trends and/or anomalies will occur. For example, the technology can recognize a person in an image and distinguish it from a rack or a box. The same software can also recognize if an operator on a forklift is distracted or not following standard procedures, such as driving without their hands on the wheel.

The system continues to learn while deployed, not only providing users with accurate data about the root causes of safety incidents as they occur but also helping to prevent future accidents based on the results from past patterns. This continuous-improvement approach allows users to operate based on leading indicators rather than responding to lagging indicators.

Holman and OneTrack began working together at two Holman warehouses in Washington State in early 2019. For the pilot program, OneTrack was looking to demonstrate the ability of its machine-learning software to deliver a measurable improvement in forklift safety and productivity that would outperform the existing, non-AI-based, legacy telemetry system that Holman had been using to track safety infractions.

The overall goal of the pilot was to determine whether or not the OneTrack system could help Holman successfully reduce the number of safety incidents occurring at the two facilities. Management was aware of several factors causing accidents including driver errors, inappropriate driver behaviors that include cell phone use while driving or aggressive maneuvering of the vehicle, and other non-driver factors such as placement of hazards in the warehouse.

Throughout the pilot, the OneTrack system was able to provide targeted data on a wide range of factors including the number of impacts and what types of impacts were occurring—i.e., impacts with machinery; with other warehouse equipment such as conveyor belts, racks, dock doors, etc.; or with pedestrians in the warehouse. Using the camera footage and real-time updates provided by the system, when an incident occurred, warehouse managers were able to instantly review the incident and proactively provide targeted driver coaching in order to improve operator behavior. The pilot program also sought to demonstrate the ability of the OneTrack system to predict, over time, when such incidents were likely to occur.

Upon completion of the pilot, Holman realized significant reductions in safety incidents and decided to move forward with the solution in its own facilities. The company also began using the OneTrack system at several client locations, including a warehousing and manufacturing plant for global CPG company Kimberly-Clark. This 440,000 square-foot-facility, located in Maumelle, Arkansas, is the production site for some of the company's leading disposable paper products.

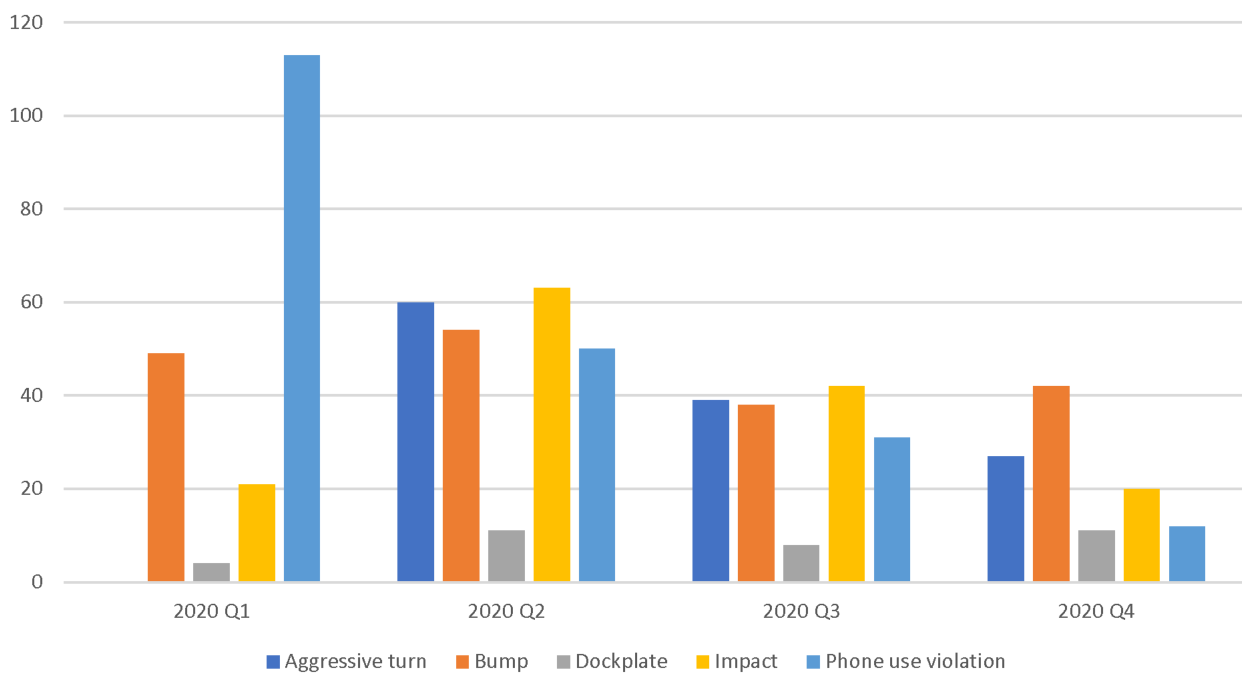
One of the challenges the Maumelle warehouse was experiencing with the existing telemetry system on its lift trucks was an inefficient "signal-to-noise" ratio: It was receiving too many alerts on non-actionable items. The non-AI legacy system was not able to differentiate between typical activities that occur in the domain of warehouse activity—such as forklift operators driving over floor cracks/bumps, debris, or dock plates—and an actual safety incident. As a result, warehouse managers were receiving far too many false-positive alerts from the system, and they were spending time focusing on inaccurate information. Because the ML-based OneTrack system is able to automatically and precisely classify each incident using AI, it delivered a higher level of data-specificity, giving managers more accurate and targeted results.

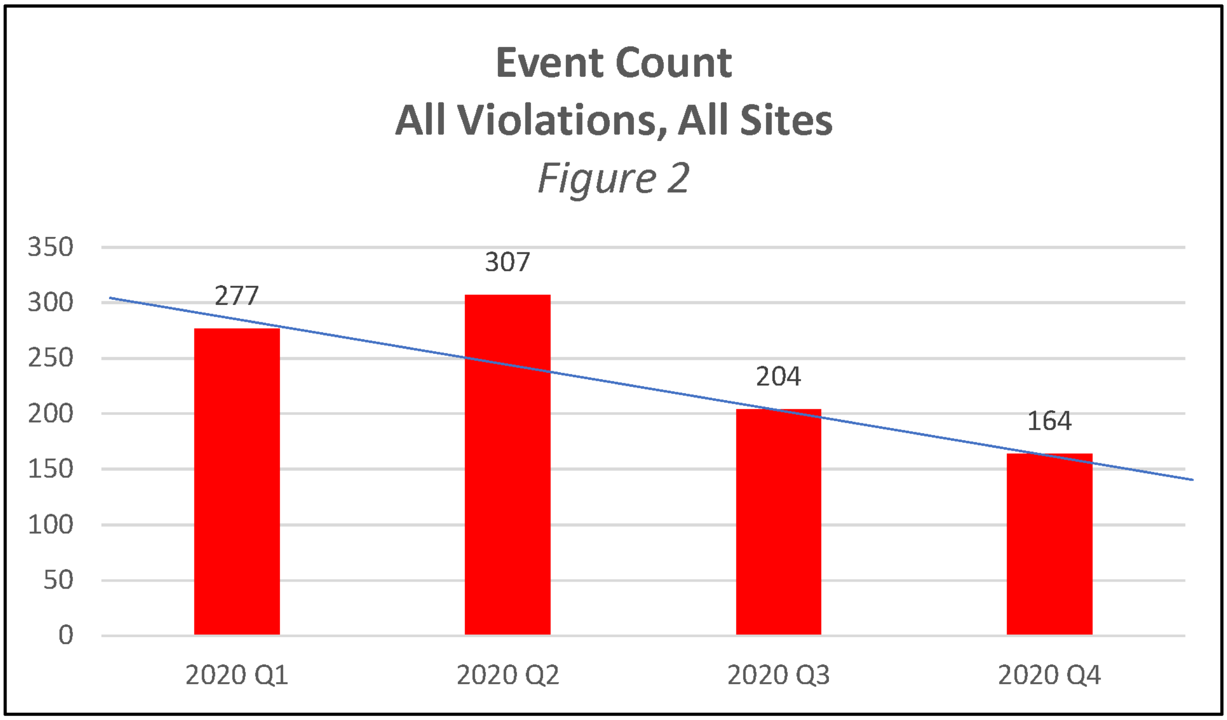
Warehouse managers at the plant cite another benefit of using the OneTrack system: The videos generated by the on-board camera offer definitive proof of the circumstances of each safety incident, making it easy to perform root-cause analyses. The videos have proven indispensable as tools for proactive driver coaching and are used during training when onboarding new operators at the facility. Combining the AI tools with an advanced focus on safety has allowed the facility to move closer to a goal of accident-free operations. One warehouse manager sums up the improvements that have resulted from implementation of the OneTrack system as follows: “Instead of being reactive when impacts occur, we can be proactive. We are alerted right as mistakes are happening—or even before they occur—so we can coach the drivers and make them better drivers before the next impact occurs.” The documented coaching also provides a feedback loop that allows for ongoing comparisons for driver behavior before and after recorded incidents have occurred.

Holman has continued to measure and monitor its safety data since implementing the OneTrack system and has seen aggregate reductions in the number of incidents in nearly every incident category. The OneTrack dashboard provides reports on key incident metrics including aggressive turns and phone-use violations, and tracks impacts, bumps (debris on the floor), and dock plate occurrences. The data sample for 2020, compiled from multiple sites, shows reductions in key incident subcategories (see Figure 1) and in aggregate for two consecutive quarters (see Figure 2).

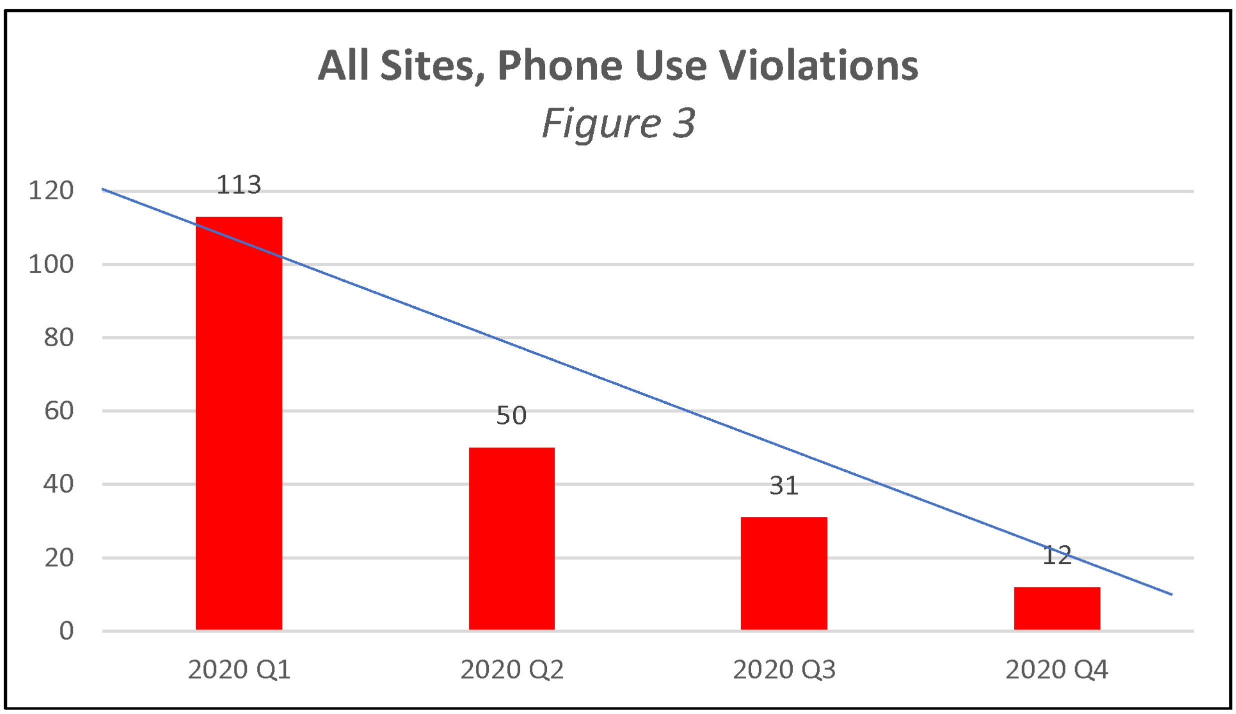
All Site Data by Event Type

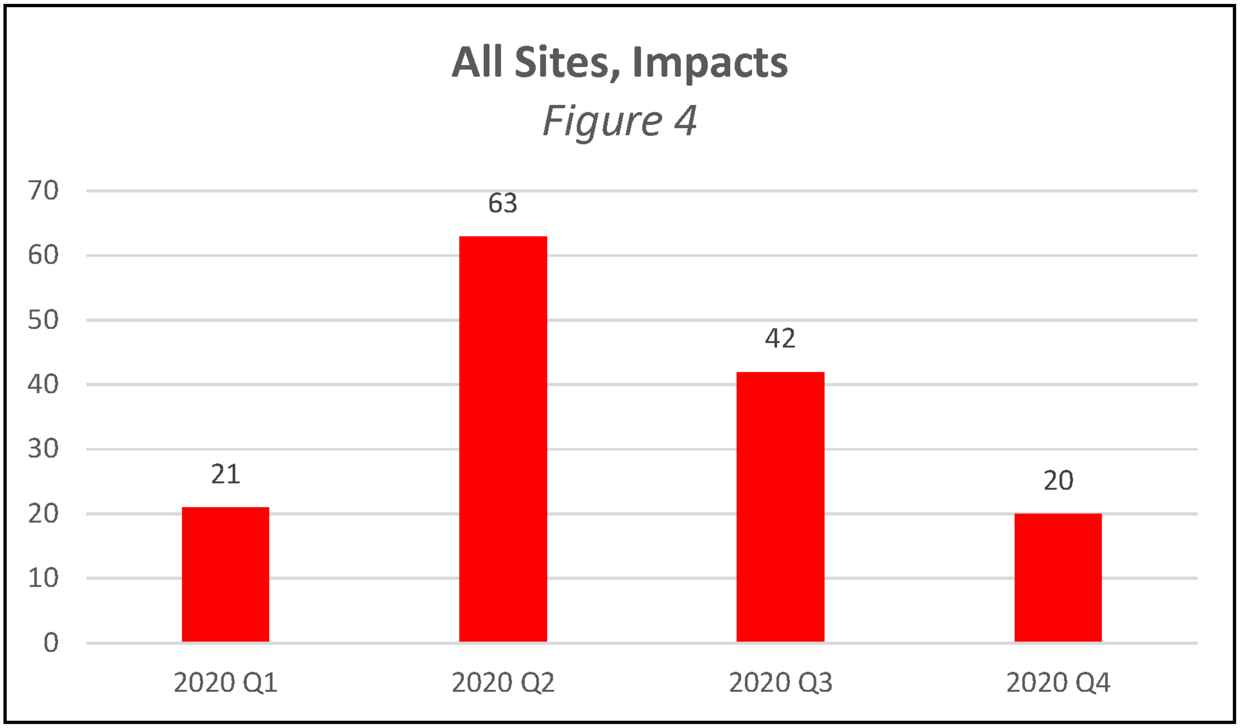
Figure 1





Holman recorded significant safety improvements in the following metrics: Cell phone violations dropped from 113 in Q1 to 12 in Q4; impacts decreased from 63 in Q2 to 19 in Q4; and aggressive turns fell from 60 in Q2 to 27 in Q4 (see Figures 3, 4, and 5).




All Sites, Impacts
Figure 4
70
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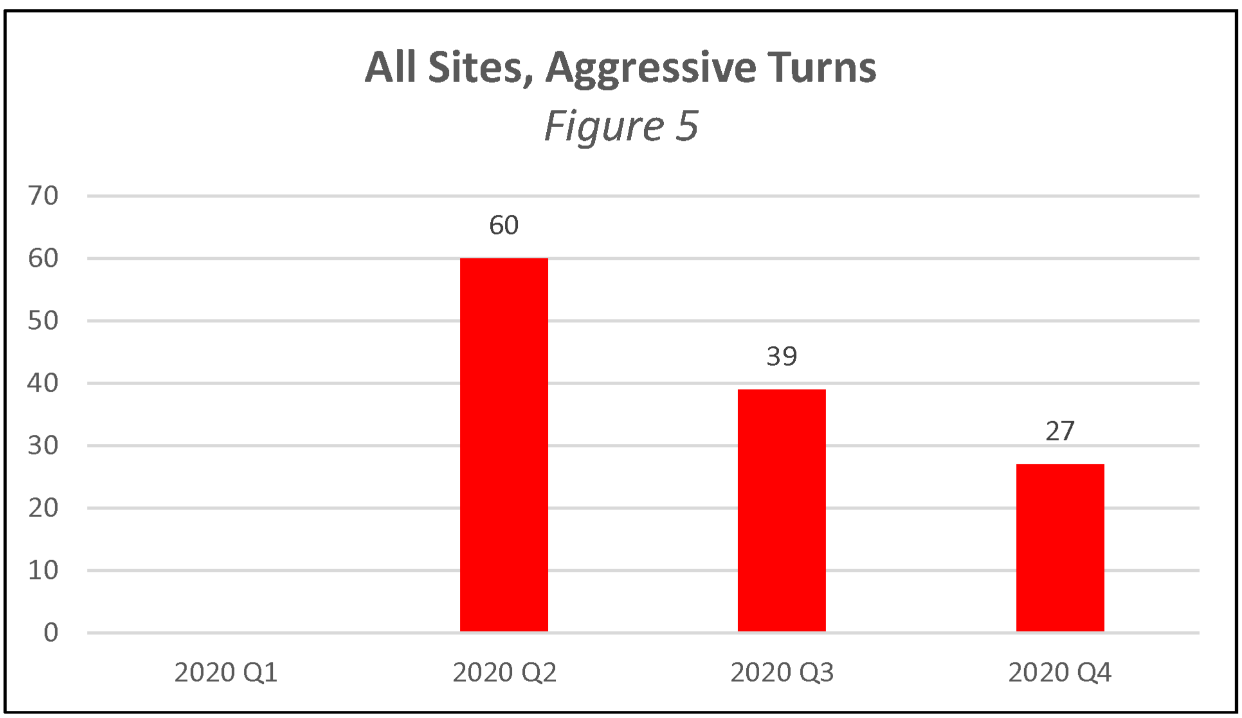
2020 Q1
2020 Q2
2020 Q3
2020 Q4


All Sites, Aggressive Turns
Figure 5
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2020 Q1
2020 Q2
2020 Q3
2020 Q4

Future Watch: What's Next for AI?
The proven enhancements to forklift safety achieved through the use of AI have led Holman Logistics to investigate other potential uses for AI technology in its operations. At its essence, AI and machine learning technologies excel at recognizing patterns and parsing large data sets, skill sets that the firm believes can be implemented effectively in the following additional ways:

- **Decreasing warehouse hazards:** Clean and orderly facilities are a hallmark of Holman operations, and the firm believes AI could help it continue to meet current benchmarks and further decrease incidences of warehouse hazards. A computer-vision AI system could be trained to recognize items that are out of place or do not belong in a facility and automatically alert the management team to potential hazards including pallets left out of the proper storage location, leaning pallet stacks, or damaged product.

- **Augmenting inventory coordination:** While a lot of attention in the industry has been focused on automating cycle counting with drones, implementing drone use in real-world scenarios is difficult and not always practical. Drone cycle counting works well only if all product is stored in single-deep racking with barcodes facing out or is equipped with RFID tags — neither of which is applicable in most real-world warehouses. A vision-based AI system connected to WMS inventory, on the other hand, could conceivably be trained to recognize product types and compare many different images of inventory in each storage location. Such a setup could potentially result in inventory-count accuracy that far surpasses human capabilities.

- **Driving continuous and automated improvements to WMS and LMS systems**: Though already proven as valuable tools for warehouse operations, WMS applications are dependent upon humans to enter information into the system. Technological improvements—such as handheld barcode-scanning devices and voice-activated tools—have increased the reliability of data entry, but human errors, such as scanning an incorrect barcode or entering the wrong quantity of items picked, still erode the overall effectiveness of WMS. In addition, managing productivity of employees has so far been dependent on manually engineered labor standards typically defined and tracked in a labor management system (LMS).

  One of the biggest challenges with traditional LMS is that defining and establishing engineered labor standards is time-consuming and expensive. Therefore, standards are adjusted infrequently, losing accuracy and relevance as the warehouses they were defined for continuously change to adapt to external factors. AI has the potential to significantly improve the capabilities of LMS by automating the detection of process and efficiency deviations in real-time, independent of manually defined labor standards. An AI-based system is capable of ingesting and combining data from all available systems: datasets about employees, transactions, and orders as well as data from sensors that track processes in the facility. With such a high-dimensional dataset, AI algorithms could learn to identify process deviations based on a combination of variables that create an anomaly.

  In this case, AI software assumes the role of a continuous improvement team and provides recommendations for changes in system configuration or process execution with the goal of optimizing for a building-wide goal-metric. What makes this approach so compelling is that goal-metrics can be tied back to bottom-line KPIs such as cost-per-unit, on-time performance, or overtime hours. Every recommendation from the system relates directly to a business objective. In the past, objectives of individual processes were often only defined in the context of each process; now it is possible to connect specific, granular on-the-floor activity with high level business KPIs.

These AI-based enhancements to WMS and LMS could yield outcomes including reductions in labor cost per unit and idle time as well as improvements in WMS utilization and pallets per man hour.

Conclusion

AI- and ML-based technologies and tools are producing a positive impact on the management of a wide array of logistics, supply chain, and manufacturing activities. Forward-looking manufacturers and distributors of finished goods and materials as well as their logistics partners who are embracing these advanced solutions and incorporating them into their regular business practices and strategies have seen measurable improvements in safety. Evidence of this lies both in practical use cases like the one presented in this paper and in the literature.

Much of the research conducted thus far on artificial intelligence in the supply chain, however, has been conducted in areas outside of the warehouse. The effect of AI tools on warehouse operations is an area ripe for further exploration and additional academic research to broaden the proven validity of AI in the warehouse and pave the way for more universal adoption of such tools.

References

(1) Kar, U., Dash, R., McMurtrey, M. & Rebman, C. (July 2019), Application of Artificial Intelligence in Automation of Supply Chain Management, *Journal of Strategic Innovation and Sustainability*, Vol. 14, No. 3.

(2) Herrmann, C., & Huang, L. (May 2020), Human-Machine Teaming in AI-Driven Supply Chains, Unpublished thesis/capstone, The Massachusetts Institute of Technology; available at https://ctl.mit.edu/pub/thesis/human-machine-teaming-ai-driven-supply-chains (accessed 26th January 2021).

(3) Toorajipour, R., Sohrabpour, V., Nazarpour, A. & Oghazi, P. (September 2020), Artificial Intelligence in Supply Chain Management: A Systematic Literature Review, *Journal of Business Research*, Vol. 22, pp. 502-517.

(4) Frayret, J.M., D'Amours, S., Rousseau, A., Harvey, S., & Gaudreault, J. (April 2007), Agent-Based Supply-Chain Planning in the Forest Products Industry, *International Journal of Flexible Manufacturing Systems*, Vol. 19, pp. 358-391.

(5) Barbuceanu, M., Teigen, R., & Fox, M. S. (1997), Agent based design and simulation of supply chain systems. In Proceedings of IEEE 6th Workshop on Enabling Technologies: Infrastructure for Collaborative Enterprises. 1997 Jun 18–20; MIT, Cambridge, MA.

(6) Avci, M. G., & Selim, H. (January 2017), A Multi-Objective, Simulation-Based Optimization Framework for Supply Chains With Premium Freights, *Expert Systems with Applications*, Vol. 67, pp. 95–106; and Wang, T., Ramik, D. M., Sabourin, C., & Madani, K. (April 2012), Intelligent Systems for Industrial Robotics: Application in Logistics Field, *Industrial Robot*, Vol. 39, pp. 251–259.

(7) Jiao, J. R., You, X., & Kumar, A. (July 2006), An Agent-Based Framework for Collaborative Negotiation in the Global Manufacturing Supply Chain Network, *Robotics and Computer-Integrated Manufacturing*, Vol. 22, pp. 239–255.

(8) Ting, S. L., Tse, Y. K., Ho, G. T. S., Chung, S. H., & Pang, G. (June 2014), Mining Logistics Data to Assure the Quality in a Sustainable Food Supply Chain: A Case in the Red Wine Industry, *International Journal of Production Economics*, Vol. 152, pp. 200–209; and Wang, J., & Yue, H. (October 2016), Food Safety Pre-Warning System Based on Data Mining for a Sustainable Food Supply Chain, *Food Control*, Vol. 73, pp. 223–229.

(9) Shaw, M. J., Subramaniam, C., Tan, G. W., & Welge, M. E. (May 2001), Knowledge Management and Data Mining for Marketing, *Decision Support Systems*, Vol. 31, pp. 127–137.

(10) Tan, K. H., Zhan, Y., Ji, G., Ye, F., & Chang, C. (July 2015), Harvesting Big Data to Enhance Supply Chain Innovation Capabilities: An Analytic Infrastructure Based on Deduction Graph, *International Journal of Production Economics*, Vol. 165, pp. 223–233.

(11) Hermann, ref 2. Above.

(12) Mahroof, K. (April 2019), A Human-Centric Perspective Exploring the Readiness Towards Smart Warehousing: The Case of a Large Retail Distribution Warehouse. *International Journal of Information Management*, Vol. 45, pp. 176-190.

(13) De Koster, René & Balk, Bert & Davelaar, I & Martens, M. (2021), Accidents Will Happen: Do Safety Systems Improve Warehouse Safety Performance? Unpublished paper, Rotterdam School of Management, Erasmus University; available at https://www.researchgate.net/publication/268415163 (accessed 26th January 2021).

(14) *Ibid.*

(15) Awolusi, I., Marks, E., & Song, S. (October 2017), Forklift Safety: Sensing the Dangers With Technology, *Professional Safety*, Vol. 62, pp. 36-39.