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Simulation for Industry 4.0

Past, Present, and Future

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ISSN 1860-5168 ISSN 2196-1735 (electronic)
Springer Series in Advanced Manufacturing
ISBN 978-3-030-04136-6 ISBN 978-3-030-04137-3 (eBook)
https://doi.org/10.1007/978-3-030-04137-3

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Foreword

I count myself lucky to have been born in the 1960s as I have experienced much of our contemporary computing history. At school, I was in the last year to use a slide rule and one of the first to use one of the new microcomputers emerging on the market. I certainly caught the "bug"—so did my Uncle! He brought an early Atari and the wonderful ZX80, the computer I really cut my programming teeth on. The ZX81 and ZX Spectrum followed as did the Sinclair QL (he wrote an inventory control system for his shop without any training!). Thanks to my parents wanting to nurture their teenage "geek", I managed to get hold of a Commodore 64, a Dragon, and an Atom. I remember buying computer magazines full of program code typing them into to whatever I could get hold of (which was always fun with the ZX Series!). In those days, we saved things onto a tape cassette player—the soundtrack of my early years was the sound of a program loading from a tape feed and quite possibly Manic Miner.

After school, I did a degree in industrial studies (I'm from Yorkshire (UK)—lots of heavy industry at the time). Computing was not a career path at the time, but things were changing rapidly. Remember this was in the mid-1980s—the twin floppy disc drive IBM PC XT had just come out. The Internet was there, but tools (and games) were difficult (but fun) to use. The degree had a small computing element, but more importantly it has a final-year module on operational research. This is where I first encountered simulation (specifically activity cycle diagrams). I could not really see me working at British Steel in Sheffield (I was completely unaware of the connection to KD Tocher at the time!) so I did a Master in Computing to try to change my career path. This was a great degree, especially as we were introduced to parallel computing. Towards the end of this, I spotted a research assistant post on speeding up manufacturing simulation with parallel computing. I applied, was successful and then spent the next few years with all sorts of simulation software, distributed simulation, and specialist parallel computing hardware (anyone remember transputers?). In the 1990s, I continued with this work at the Centre for Parallel Computing at the now University of Westminster (with whom I still work) and the great people in my Modelling and Simulation Group at Brunel University London and many collaborations with friends across the world.

It has been a fascinating time—experiencing the impact of the World Wide Web, new enterprise computing architectures, multicore computers, virtualization, cloud computing, the Internet of things and now the rise of big data, machine learning, and artificial intelligence (AI).

What I find remarkable is that every new advance in digital technology has been closely followed by some new simulation innovation. Researchers exploited the new personal computers of the 1980s with new simulation environments, the World Wide Web with Web-based simulation, distributed computing and high-performance computing technologies with parallel and distributed simulation, etc. These advances have been continuous and overall have strongly influenced and led to the evolution of mainstream commercial simulation. The digital technology of Industry 4.0 is especially exciting. Arguably, it has been made possible by the relative ease of interoperability between elements of cyber-physical systems such as automation, data infrastructures, the Internet of things, cloud computing, and AI. This new "Industrial Revolution" has tremendous potential for the world, and given the above trend, I am confident that this will be followed closely by new, creative advances in simulation that will further fuel the revolution. This book captures the state of the art of simulation in Industry 4.0, and I am sure it will inspire and inform many new innovations in this golden age of technology.

Greater Yorkshire, UK Prof. Simon J. E. Taylor
February 2019

Preface

Technological developments have transformed manufacturing and caused industrial revolutions. Today, we are witnessing an Industrial Revolution so-called Industry 4.0. The name was coined in Germany in 2011, and later many countries adopted the idea and created programs to shape manufacturing for the future. The future of manufacturing is about smart, autonomous, and linked systems, and custom and smart products.

Industry 4.0, the Fourth Industrial Revolution, comprises of advanced technologies such as robotics, autonomous production and transportation machinery, additive manufacturing, Internet of things (IoT), 5G mobile communication, sensors, integration of systems, the cloud, big data, data analytics, and simulation. These technologies are used for increasing product quality and diversity, optimizing processes, and decreasing costs with smart systems. The goals of Industry 4.0 are to achieve smart factories and cyber-physical systems (CPSs).

Simulation has been used in manufacturing since its birth in the 1950s for understanding, improving, and optimizing manufacturing systems. Many techniques, methods, and software for simulation including, but not limited to, discrete-event simulation (DES), system dynamics (SD), agent-based simulation (ABS), simulation optimization methods, heuristic algorithms, animation, and visualization techniques have been developed and evolved in years.

This book is written to signify the role of simulation in Industry 4.0 and enlighten the stakeholders of the industries of the future. The Fourth Industrial Revolution benefits from simulation for supporting developments and implementations of manufacturing technologies associated with Industry 4.0. Simulation is directly related to CPS, digital twin, vertical and horizontal system integration, augmented reality/virtual reality (AR/VR), the cloud, big data analytics, IoT, and additive manufacturing. This book is organized around related technologies and their intersection with simulation.

I see *simulation* at the heart of Industry 4.0. As we get more digitized, we will see more simulations in the future. New uses of and the need for simulation will emerge in manufacturing in Industry 4.0 era, and simulation research and development community will respond accordingly with new approaches, methods, and applications.

Istanbul, Turkey
February 2019

Murat M. Gunal

Acknowledgement of Reviewers

I am grateful to the following people for the support in improving the quality of the chapters in this book (the list is sorted by first names).

Andreas Tolk, MITRE Corporation, USA
Burak Günal, Freelance Consultant, Turkey
Enver Yücesan, INSEAD, France
Iván Castilla Rodríguez, Universidad de La Laguna, Spain
Kadir Alpaslan Demir, Turkish Naval Research Center Command, Turkey
Korina Katsaliaki, International Hellenic University, Greece
Lee W. Schruben, University of California at Berkeley, USA
Muhammet Gül, Tunceli University, Turkey
Mumtaz Karatas, National Defense University, Turkey
Navonil Mustafee, University of Exeter, UK
Rafael Arnay del Arco, Universidad de La Laguna, Spain

About This Book

The book shows how simulation's long history and close ties to industry since the Third Industrial Revolution have led to its growing importance in Industry 4.0. It also emphasizes the role of simulation in the New Industrial Revolution, and its application as a key aspect of making Industry 4.0 a reality—and thus achieving the complete digitization of manufacturing and business. It presents various perspectives on simulation and demonstrates its applications, from augmented or virtual reality to process engineering, and from quantum computing to intelligent management.

Simulation for Industry 4.0 is a guide and milestone for the simulation community, as well as for readers working to achieve the goals of Industry 4.0. The connections between simulation and Industry 4.0 drawn here will be of interest not only to beginners, but also to practitioners and researchers as a point of departure in the subject, and as a guide for new lines of study.

Chapter "Simulation and the Fourth Industrial Revolution" is the introductory chapter which sets up the scene for the book and gives a background information including a historical review of the industrial revolutions and historical perspective of simulation. Concepts within Industry 4.0 are introduced, and their interaction with simulation is evaluated. This chapter reveals that simulation has a significant role in Industry 4.0 concepts such as cyber-physical systems (CPSs), augmented reality/virtual reality (AR/VR), and data analytics. Its role will continue in analysis for supply chains, lean manufacturing and for training people.

Chapter "Industry 4.0, Digitisation in Manufacturing, and Simulation: A Review of the Literature" is a review of the literature written by Gunal and Karatas (2019). Their review is conducted in two parts; first, selected publications between 2011 and 2019 are critically evaluated, and second, Google Scholar is used to count studies with selected keywords. Their review revealed that the number of papers on Industry 4.0 increased exponentially in recent years and these papers are not only from Europe but also from other countries in the world. This suggests that "Industry 4.0" is adopted by the whole world.

Chapter "Traditional Simulation Applications in Industry 4.0" is presenting traditional simulation applications in Industry 4.0, written by Sturrock (2019).

He emphasizes that DES products are routinely used for purposes supply chain logistics, transportation, staffing, capital investment, and productivity. He presents case studies in health care, iron foundry, logistics, and manufacturing. He discusses that a smart factory can benefit from simulation to assess the impact of any specific advanced features. Furthermore, with DES, decision-makers can identify areas of risks before implementation and evaluate the performance of alternatives. He also gives a tutorial for building a simple model using Simio simulation software. In this model, a simple production system is built. A Gantt chart is generated and optimized for scheduling which is an important feature desired in smart factories of the future.

Chapter "Distributed Simulation of Supply Chains in the Industry 4.0 Era: A State of the Art Field Overview" is discussing distributed simulation of supply chains in Industry 4.0 context and written by Katsaliaki and Mustafee (2019). They highlight the significance of distributed simulation for supply chain analysis and review simulation techniques including parallel simulation, DES, ABS, and SD. They present distributed simulation around two scenarios, first as an enabler of large and complex supply chain models, and second, as an enabler of inter-organizational supply chain models. Although they point out that parallel DES is dominant in most of the studies, potential of ABS and hybrid modelling is great in terms of modelling autonomy, complexity, and scalability in the problem domain.

Chapter "Product Delivery and Simulation for Industry 4.0" is debating on product delivery and simulation issues in Industry 4.0 context, written by Cruz-Mejia, Marquez, and Monsreal-Berrera (2019). They propose "Smart Coordinated Delivery" (SCD) within supply chain players to re-balance the workload and increase the efficiency. Simulation can be used to assess the performance of SCD and to help design "standard interfaces" to enable coordination. They put forward "merge in transit" operations are needed to consolidate multi-item shipments, and this could be implemented using technology such as IoT. The role of simulation here is to help design such systems since simulation is a powerful tool when data availability is limited or problematic. For improving the "last mile delivery" performance, the authors highlight the potential of "what3words.com" concept and using VR/AR. Furthermore, ABS is mentioned as an excellent option for business modelling since it is about autonomous decision-making entities as in the real-life examples. They point out that simulation software vendors should adapt the software to Industry 4.0 to answer the needs emerged by the new concepts. For example, a new dynamic and intelligent queueing objects must exist in the software to mimic smart factory operations such as picking the next part to process on a machine from a que of jobs with some prespecified rule.

Chapter "Sustainability Analysis in Industry 4.0 Using Computer Modelling and Simulation" is written by Fakhimi and Mustafee (2019) and is discussing sustainability in manufacturing and supply chain systems from Industry 4.0 and modelling and simulation point of views. They point out that modelling and simulation techniques could provide significant insights in coping with the uncertainty associated with triple-bottom-line (TBL) management and highlight that there are opportunities for the realization of sustainable development in using simulation in Industry 4.0.

Chapter "Interactive Virtual Reality-Based Simulation Model Equipped with Collision-Preventive Feature in Automated Robotic Sites" is written by Alasti, Elahi, and Mohammadpour (2019) and demonstrates how a DES model of a manufacturing facility with robot arms can work with a robot arm simulation software. The VR created can help design robot operations in a facility. Their approach is a template for modelling manufacturing with robots. This chapter also summarizes the use of VR in manufacturing including in design and prototyping phase, planning phase, simulation, workforce training, machining process, assembly, inspection, and maintenance phases.

Chapter "IoT Integration in Manufacturing Processes" presents an implementation Event Graphs methodology called TAO, written by Adduri (2019). A novel feature is the "pending edge" which is an entry to Future Event List (FEL). TAO allows editing FEL in simulation. An event can be scheduled when an earlier event is scheduled. This feature can be useful in cases such as an IoT device is to be fed to a simulation model. Real-time data, for example provided from IoT devices, could be used in models. Simulation is suggested as a production management software rather than being a tool to design the production system. This way of use is a novel approach.

Chapter "Data Collection Inside Industrial Facilities with Autonomous Drones" is a conceptual study of a drone-based data acquisition and processing system, written by Gunal (2019). To achieve Industry 4.0 targets, a manufacturing facility can benefit from such system in sensing and collecting data at the shop floor. In the proposed system, there is an autonomous drone which can fly over predefined path inside a facility and collect visual data. The data is processed on the return, and useful managerial information is obtained by processing vision data. The system can be a solution for SMEs to increase their Industry 4.0 maturity levels.

Chapter "Symbiotic Simulation System (S3) for Industry 4.0" is presenting symbiotic simulation system (S3) and written by Onggo (2019). S3 is a tool designed to support decision-making at the operational management level by making use of real-time or near-real-time data which is fed into the simulation at run-time. Symbiotic simulation is very relevant to Industry 4.0 as it makes use of real-time data, and can be a significant part in CPS. This chapter includes the architecture of S3, three types of S3 applications for Industry 4.0, and challenges for adoption.

Chapter "High Speed Simulation Analytics" is written by Taylor, Anagnostou, and Kiss (2019) and presents high-speed simulation analytics from an Industry 4.0 perspective. They see that distributed simulation and high-speed experimentation with cloud computing are the keys to achieve high-speed analytics. A novel commercial system has been presented that demonstrates how cloud computing can be used to speed up simulation experimentation. This chapter highlights the role of simulation in data analytics as one of the comprising technologies of Industry 4.0.

Chapter "Using Commercial Software to Create a Digital Twin" is presenting how a digital twin using a commercial simulation software can be constructed, and written by Sturrock (2019). First, he discusses the digital twin concepts and how it addresses the challenges of Industry 4.0. Secondly, he evaluates how modern simulation software can be used to create a digital twin of the entire factory. Finally, Risk-based Planning and Scheduling (RPS) system which provides a unique solution to achieve smart factory is presented.

Chapter "Virtual Simulation Model of the New Boeing Sheffield Facility" is presenting a virtual simulation model of Boeing Company's facility in Sheffield, UK, and written by Hughes (2019). The factory is expected to become an Industry 4.0 flagship facility for Boeing, with robust IT infrastructure and a fully connected virtual simulation model working between its digital and physical systems—a "digital twin" factory. The digital twin is built using commercial simulation software. This chapter presents the key elements in the simulation model and discusses the approach of linking the model to physical systems.

Chapter "Use of a Simulation Environment and Metaheuristic Algorithm for Human Resource Management in a Cyber-Physical System" is a study conducted on workforce planning problems in Industry 4.0 and written by Hankun, Borut, Shifeng, and Robert (2019). They presented 5C CPS architectural model and applied five-level architecture implemented with simulation. Heuristic Kalman algorithm (HKA) and improved HKA are presented as evolutionary methods for determining the number of workers in a virtual factory. They demonstrated the benefits of these algorithms with a simulation model. Their algorithms can help determine an optimum number of workers in a CPS.

Chapter "Smart Combat Simulations in Terms of Industry 4.0" is presenting the concepts in military and their links with Industry 4.0, from Command, Control, Computer, Communication, Intelligence, Surveillance, and Reconnaissance (C4ISR) point of view, and written by Hocaoglu and Genc (2019). Their study shows that data sharing, fusing data received from different sources, distributed decision, automated decision-making, integration of systems, and handling big amount of data are common points for both C4ISR and Industry 4.0. They also discussed agent-based simulation technologies and demonstrated an application of C4ISR concepts in a simulation environment.

Chapter "Simulation for the Better: The Future in Industry 4.0" is the final chapter and a conclusion of the book, written by Gunal (2019). This chapter states the role of simulation in Industry 4.0 era and links the concepts of Industry 4.0 with simulation. A discussion is included on how simulation can contribute to designing, developing, and improving manufacturing systems of the future.

Contents

Editor and Contributors

About the Editor

Murat M. Gunal is working in simulation and operational research (O.R.) since 1999. He received his M.Sc. and Ph.D. degrees in O.R. from Lancaster University, UK, in 2000 and 2008, respectively. His main area of research is simulation methodology and applications particularly in health care, service sector, and the industry. His Ph.D. thesis was funded by EPSRC and titled District General Hospital Performance Simulation. His simulation models are being used in various National Health Service (NHS) hospitals in the UK for performance improvements. In his M.Sc. study, he wrote a dissertation on call center operations and developed a simulation model for NTL digital TV company. He took part in research projects funded by Istanbul Metropolitan Municipality, Turkish Science and Technology Research Council (TUBITAK), and Ministry of Health in Turkey. He conducts research and works in consultancy projects for industrial, health care, and service systems.

He published scholarly papers in academic journals and chapters in edited books. He also attends conferences regularly and publishes at conference proceedings including Winter Simulation Conference (WSC) and Spring Simulation Conference. He has one book translation published in Turkish.

He worked as Associate Professor at Barbaros Naval Science and Engineering Institute, in Turkey, and was Director of Master of Science in Naval Operational Research. He taught simulation, probability, facility planning, service science, decision analysis, mathematical modelling, and O.R. applications at graduate and undergraduate levels in several universities in Istanbul since 2008. He is Associate Editors of *Journal of Simulation* and *Health Systems*.

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Abbreviations

ABS	Agent-based simulation
AGV	Automatic guided vehicle
AI	Artificial intelligence
AR	Augmented reality
BDI	Belief, desire, intention
C4ISR	Command, Control, Computer, Communication, Intelligence, Surveillance, and Reconnaissance
CDM	Content distribution management
CPS	Cyber-physical system
CV	Computer vision
DA	Data analytics
DES	Discrete-event simulation
DIS	Distributed Interactive Simulation
DSCS	Distributed supply chain simulation
DVE	Distributed virtual environments
ERP	Enterprise resource planning
HKA	Heuristic Kalman algorithm
HLA	High-level architecture
HRM	Human resource management
ICT	Information and communication technologies
IoT	Internet of things
KPI	Key performance indicator
MCS	Monte Carlo simulation
MES	Manufacturing execution system
MIS	Manufacturing information system
ML	Machine learning
MR	Mixed reality
PADS	Parallel and distributed simulation
RFID	Radio-frequency identification
RTI	Run-time infrastructure

S2	Symbiotic simulation
S2M	Symbiotic simulation model
S3	Symbiotic simulation system
SaaS	Software-as-a-service
SBL	Scenario-based learning
SCM	Supply-chain management
SD	System dynamics
SDEV	Sustainable development
SME	Small and medium-sized enterprise
SOA	Service-oriented architecture
SOM	Sustainable Operations Management
TBL	Triple bottom line
UAV	Unmanned aerial vehicle
URL	Unified Modeling Language
VR	Virtual reality
WSC	Winter Simulation Conference
XML	Extensible Markup Language

Product Delivery and Simulation for Industry 4.0

Oliverio Cruz-Mejía, Alberto Márquez and Mario M. Monsreal-Berrera

Abstract Industry 4.0 is having machines working connected as a collaborative community, both inside and outside the walls of the manufacturing sites. Manufacturing, sourcing, and delivery supply chains are now connected, making synchronization possible. Physical product delivery has changed significantly. Smart deliveries are now possible by directing end customer location in dynamic conditions. The capabilities of the delivery system can be simulated using discrete event simulation to compromise on-time delivery. Big data analytics are now a fundamental tool for product delivery analysis of optimal vehicle routing conditions and resource allocation. As companies have improved product delivery capabilities, more complex supply chains have been created. Analytic tools can tackle this complexity in estimating delivery time and product delivery windows under different workload scenarios.

Keywords Product delivery · Computer simulation · Lead-time analysis · Discrete-event simulation · Last mile delivery

1 Introduction

The technologies of Industry 4.0 (sensors, big data, analytics, artificial intelligence) blur the lines between the digital and physical world. In a world that demands better customer service and transparency, knowing product and resources locations in real time gives power to manufacturers and distributors in modern supply chains.

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M. M. Gunal (ed.) *Simulation for Industry 4.0*, Springer Series in Advanced Manufacturing, https://doi.org/10.1007/978-3-030-04137-3_5

These technologies facilitate real-time system status, including orders, product, availability of transportation resources, and availability of storage resources. Simulation can be used to model the impact of implementing Industry 4.0 technologies in resource coordination. For instance, delivery on the last mile means coordinating the picking of different products to assemble the order [1]. Trucks, lift trucks, hand picking personnel, product, and order information may all have to be present in a coordinated fashion to pick the product from the warehouse and prepare the shipment. The current operations decision-making process is to independently schedule each resource. In case of conflicts, priority rules are used to solved conflicts. In Petersen and Aase [2], results show that order batching yields the greatest savings, particularly when smaller order sizes are common. Results also show using either a class-based or volume-based storage policy provides nearly the same savings as batching, while being less sensitive to the average order size. In other cases [3] heuristics can enhance order picking efficiency when they replace a simple first-come-first-serve method.

2 Applications of Simulation in Real World Product Delivery

Industry 4.0 promises a more coordinated work where rather than conflict, resources work in unison, as if simultaneously orchestrated to be in a specific place at a particular time. Simulation can be used to optimize the number of resources that increases productivity, without blocking each other or designing optimal workload for type of product, location of the product for order assembly, etc. This type of coordinated effort will require simulation packages, which instead of solving conflicts by queues, use an advanced logic to emulate resources coordination. Simulation packages today depend on the user to create advance logic subroutines to control any type of sophisticated coordination. In the future, key coordination algorithms may be available off the shelf to be implemented both in simulation and the Industry 4.0 real world.

Barreto et al. [4] explain that Industry 4.0 logistics will highly need transparency (supply chain visibility) and integrity control (right products at the right time, place, quality condition, and at the right cost) in the supply chains. For distribution, new coordination schemes could be simulated, including smart coordinated delivery using fleets that re-balance the workload using the latest information available within the system.

These coordination efforts could include disruptions in the distribution network. For instance, in the case of road blockage due to accidents, the best algorithms for re-routing and re-scheduling in real time can be tested in a simulated environment. Similarly, extreme weather conditions (rain, fog, snow) can be simulated to test the system under stress. During Hurricane Harvey, large parts of the state of Texas were affected. The simulation of how the water would affect the roads and when would have allowed a better response. Some places were inundated; others did not

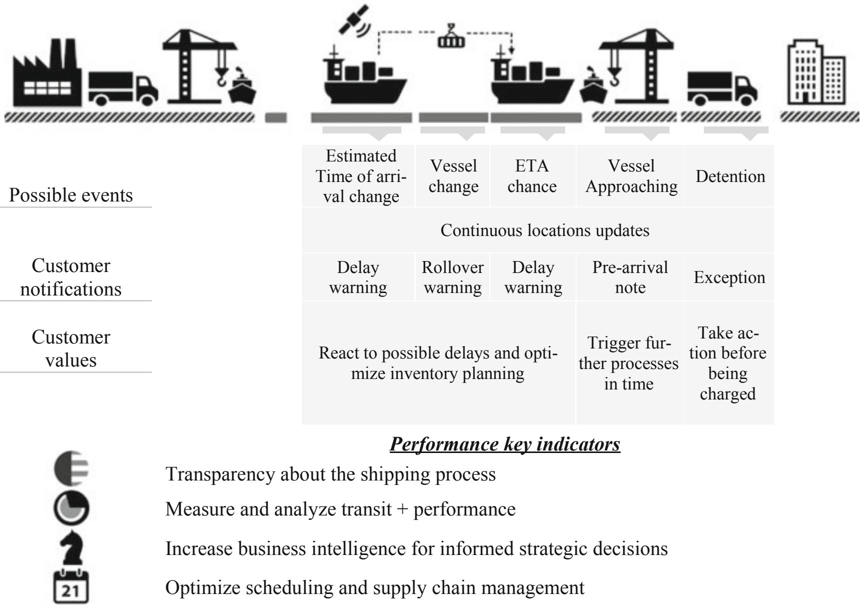

Fig. 1 Smart coordinated delivery

have potable water. Anticipating losing running water would have prevented water shortages, reducing the population distress during the peak of the predicament.

Figure 1 shows a prototypical supply chain that is fully integrated and coordinated. In the figure, the sharing of valuable information in real time can help stakeholders in the whole supply chain. An example can be the estimated arrival time of a product; this time can change due to weather conditions or delays so delivery systems are able to update shipment locations and provide notifications to the companies linked in the supply chain. Customers value this flow of information as the supply chain can react to inventory planning conditions and trigger contingency plans if needed.

Another important aspect under consideration is the environmental impact of distribution. Simulation can be used to predict air quality, noise, and waste products, especially with sensors and other technologies of Industry 4.0. Some efforts have been made to address the opportunities and gaps to integrate environmental protection and Industry 4.0 [5]. Smart deliveries and coordination can be simulated to reduce the environmental impact of last mile delivery, reducing carbon dioxide emissions [6].

Societal impact and quality of life can also be included. Fast delivery can be a life or death situation. Simulation could consider accidents, safety standards, reverse logistics, and similar efforts to improve the standard of living.

Naturally, the development of smart algorithms is expected to have an evolution, as the technology is improved, better coordination between players is implemented, and smarter decisions can be built into the system. Researchers have proposed that

Industry 4.0 will have self-optimization and self-training behaviors [7]. Simulation can model the introduction of the scheduling and coordination algorithms from the simplest to the most sophisticated, effectively helping the self-optimization and self-training algorithms.

Particularly the delivery of foods [8], drugs DNA and other biological samples, and other sensitive material can be improved with Industry 4.0. Simulating the delivery of these specialized supply chains will promote the rapid development of policies and algorithms to fully integrate and coordinate its agents.

3 Smart Deliveries

As traditional manufacturing is transferred to developing countries, advanced countries move to higher value supply chains. That means it will be ever more important to track individual products with utmost precision. GPS is a standard feature included in logistic coordination of vehicles and tracking cargo at the bulk level. In the future, combining conventional transaction tracking (bar code and RFID) blockchain and GPS technologies, along with omnipresence of sensors, promise an unparalleled product tracking capability. Simulating tracking an individual product will allow for better planning for the cases where a robust response on tracking is needed (Fig. 2). How do we design a system that, even in the case of misinformation, each product can be tracked back in the path without making it very costly or redundant?

Industry 4.0 technologies could factor in fuel efficiency, cost effective solutions for delivery, and self-driving vehicles to determine the most cost effective route and acceleration and deceleration patterns. Then the algorithms, routes, and implementation could be tested using the virtual spaces created by simulation.

Capital expenditure in last mile delivery equipment can be justified by using simulation. The integration of new capabilities can be scaled or scheduled in a progressive way, indicating the possible scenarios in which to introduce new features that will coordinate final delivery with other functions within the supply chain. Further, the financial justification for additional capital needed in implementing Industry 4.0 technologies requires computing its positive impact.

With the implementation of Industry 4.0 technologies, researchers expect the infrastructure (roads, bridges, ports, airports, etc.) will integrate this technology too, motivated by higher efficiency, safety, and the proven interfaces between the different users of such infrastructure. Simulation of the coordination enabled by Industry 4.0 infrastructure can help in designing standard interfaces and can justify the prioritization of Industry 4.0 capabilities in current and future infrastructure investments.

On a global scale, a recent development that promises to change the nonurban delivery of products is the concept of what3words location. This is a 3×3 m location capability for the whole surface of the earth. The idea is that every 3×3 m can be identified by simply using three consecutive words in the English language. The number of possible combination of words allows for all the 3×3 m sections to be individually tagged in a grid that covers the planet. This adds precision for all

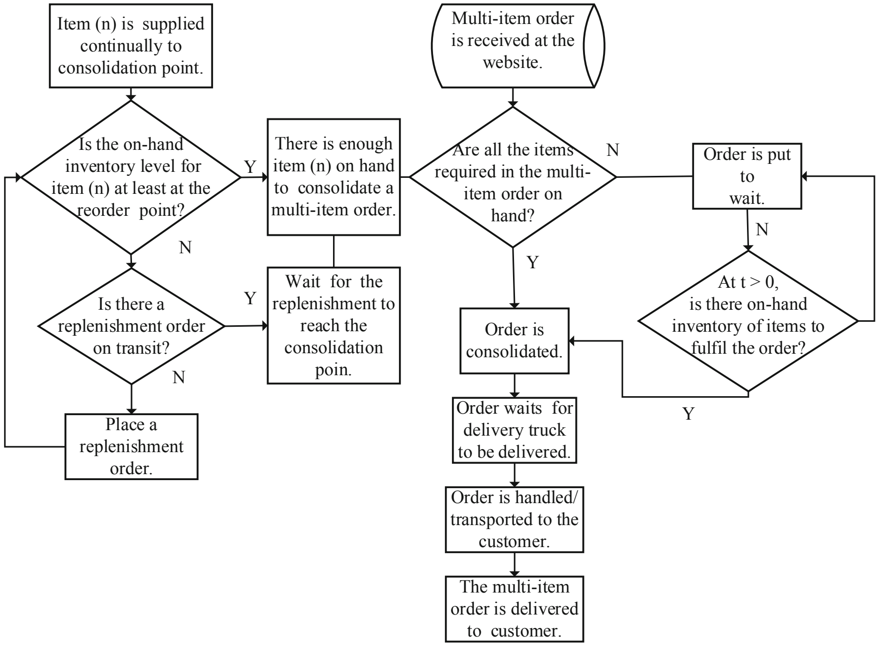

Fig. 2 Multi-item consolidation flow diagram

sorts of potential last mile delivery in nonurban settings, where there may not be even a road, address, post office, or mailbox. This, combined with drones, GPS, and other capabilities bring nonurban settings to modern times without the need for a conventional address. Naturally this will improve the last mile delivery performance under those settings. It is conceivable that simulation packages can have a default setting for what3words.com to simulate the requirement of an efficient delivery of nonrural areas.

Multimodal last mile delivery is not impossible in settings where ferries are needed or at least are an option to be considered. Simulation of this transportation mode can be simulated, creating the most coordinated system possible.

With augmented reality and virtual reality (AR/VR), simulation packages can be used for design and training operations. Companies can use simulation-based games to train their personnel on human interaction with clients, assessing issues and solutions of different positions, etc.

Using simulation for product delivery optimization will have to take into consideration the requirements for creating new added value in the long run, while remaining competitive with optimized operations in the short term. Simulation then will be used to anticipate the potential impact of new technological proposals implemented first in an exclusively virtual world and then deployed in the digitized world of Industry 4.0. In the short term, simulation can help synchronize the organizational resources in real time, maximizing the potential of sensors and the capacity for interconnection.

With the digitization of the economy, many changes are happening in the retail and last mile delivery domain. Brick and mortar stores are reducing their pedestrian traffic and revenue, while multiproduct and automated warehouses are growing in number, size, and sophistication. Miyatake et al. [9] used simulation for comparing the cost of online shopping versus brick and mortar stores. Their conclusion was that an online store saved in rent and labor costs.

For the future, value added operations near the customer will create a white glove service, in which companies can deliver prime branding products using the benefits of integrated coordinated logistics. These value-added activities will require fast and efficient training. AR/VR capabilities will enable the required sophistication of the operations through training and anticipating customer needs. Simulation will include virtual spaces and virtual-real interaction.

With the transformation of the economy, an important change is the need for hassle-free returns. Supply chain optimization will include the reverse logistics both for customer service and good sustainable practices. The typical challenges for expanding reverse logistics include the lack of real-time accurate logistics information and demands toward sustainable operations logistics [10]. Liu et al. [10] suggest a bottom-up logistics strategy that aims to achieve the real-time information-driven dynamic optimization distribution for logistics tasks. They propose an Internet of Things (IoT)-enabled real-time information sensing model designed to sense and capture the real-time data of logistics resources, which are shared among companies after the value-added processes. The main idea is to use a real-time information-driven dynamic optimization to optimize the configuration of logistics resources, reduce logistics cost, energy consumption and the distribution distance, and alleviate the environmental pollution. With this contribution in mind, reverse logistic policies can be tested using simulation. The optimization algorithms can be customized and tested using simulation.

4 Big Data Analytics and Artificial Intelligence for Product Deliveries

Artificial intelligence, big data, and analytics will combine with sensors and connectivity, enabling the representation of virtual worlds for simulation. Simulation packages today already come prepared for system design optimization of several resources, transporters, and other parameters. Simulation will have to keep integrating continuous improvement processes into their packages. In product delivery, smart agents will synchronize activities and products, creating a seamless operation in customers' eyes. Such synchronization algorithms will be common in the market place as the IoT and Industry 4.0 becomes the standard. In order to make the simulation packages relevant, the same synchronization algorithms will have to be available for the simulation software packages off the shelf to be ready to be applied for long-term planning and short-term operation optimization.

Additional new technologies will create new models of delivery operations. Self-driving vehicles and drone delivery are promising to be available soon. AR/VR could help the final user be prepared to make full use of the features of the product that is yet to be delivered in the physical world. Simulation will be present in the creation of this anticipated customer experience. Blockchain technologies will bring trust, increased security, removal of middlemen, and faster transactions. In the competitive market, simulators will have to integrate to the criteria the speed of the transactions, and tracking capability, that block chain bring to the table where the shake of hands at each transaction is important for security and validation purposes.

Industry 4.0 will affect how inventories are managed just before or at the delivery to the client. Concepts like vendor managed inventory will turn into autonomous inventory management with the help of sensors and interconnectedness. The next step will be predictive logistics based on integrating artificial intelligence in the decision-making process. Similarly, automated warehouse operations will yield to automated warehouse networks, and eventually it is possible to conceive synchronic distribution without an intermediate warehouse. The simulation of this highly sophisticated alternative will require more than randomized events within simulation but should bring the same capabilities of artificial intelligence coordination within the simulation models.

5 Internet of Things and Delivery Supply Chains

In the context of Industry 4.0, the IoT is progressively getting public and private sector attention to increase supply chain performance and boost economic growth [11]. The major evolutionary change promised by the IoT is the integration of networks that contain sensor and tracking devices, also known as Auto-ID technologies. The IoT enables each device to be directly accessible through the Internet. For example, RFID has been used for years to track products through certain parts of the supply chain. However, once the product left the shelf of a retail outlet, the manufacturer's ability to track the object was lost. Likewise, consumers were unable to gain access to the lifecycle information of products they purchased. In the IoT concept, devices can communicate with one another with point-to-point, point-to-multipoint, or multipoint-to-multipoint communication. By giving each product a unique identifier and making its data available through the web, the IoT promises to enable product traceability throughout the entire product lifecycle [12].

The IoT will also change the way businesses interact with customers and receive feedback about products [13]. Therefore, the use of the IoT concept and Information and Communication Technologies (ICTs) is considered a valuable asset in supply chain management because it enables seamless communication throughout different levels of the supply chain. With the advent of IoT, Internet connections now extend to physical objects that are not computers in the classic sense and serve a multiplicity of other purposes.

One main purpose of this seamless communication is the measurement of supply chain performance to provide precise and on-time decision-making information. Product delivery, which is the ultimate supply chain activity where the overall performance of the supply chain, reflects if anything that went wrong upstream the supply chain (lack of delivery being the worst-case scenario). Research firm Gartner states that the IoT will dramatically change delivery operations. By the year 2020, 30 times more Internet connected physical devices will significantly alter how the supply chain works [14]. Morgan Stanley estimates that 75 billion devices will be connected to the IoT by 2020 [14].

With the exponential growth of e-business, a lot of pressure is put on product delivery and its supporting activities, especially on the online transaction process: The relationship between e-retailers and product delivery service providers is complicated mainly due to the online transaction process. E-retailers and product delivery service providers are partners. Yet e-retailers are evaluated by end customers, whose satisfaction level is of essence for returning to the same e-retailer.

There are several examples of IoT used to improve product delivery. For instance, Yu et al. [14] integrated the IoT with innovative selection criteria for a product delivery service supplier, using the Asset-Process-Performance framework and a triadic model that includes e-retailers, product delivery service providers, and customers. Figure 3 shows a diagram on how the merge-in-transit operations need to be executed for the coordination of consolidated multi-item shipments. The flow diagram can be read from left to right beginning with the product sourcing operations. The system can track both make-to-order and make-to-stock products that will be assembled downstream in the supply chain. Sourcing policy and transportation time are key elements to be evaluated. After that, the merging operation takes place were orders are configured according to purchase orders. Finally, the order delivery operations are scheduled according the customer needs.

"This study finds that flexibility is a key criterion that will strengthen the relationship between e-retailers and product delivery service providers to improve the competitiveness of e-retailers as well as to satisfy the customers" [14]. Despite that various practitioners' guidelines have highlighted the importance of infrastructure and flexibility for product delivery service providers, this is one of the first studies that provides theoretical foundations and empirical validations of these general opinions. In addition, this study's framework proves the suggestions in previous studies that the combination effect of hard infrastructure assets and soft infrastructure assets have positive influence on flexibility, which in turn has a positive impact on customer satisfaction.

One of the factors preventing a more rapid adoption of the IoT and a wider spread of the Industry 4.0 concept in activities such as product delivery is the lack of understanding of new technologies. However, the understanding of the IoT concept can be increased by demonstrating its impacts and benefits on supply chain performance. Given the omnipresent challenge of data constraints, developing a thorough comprehension of the IoT concept and its impacts on supply chain performance could be better accomplished by simulation. Simulation is a powerful tool that helps when data availability is limited or problematic. Also, simulations are adequate to study

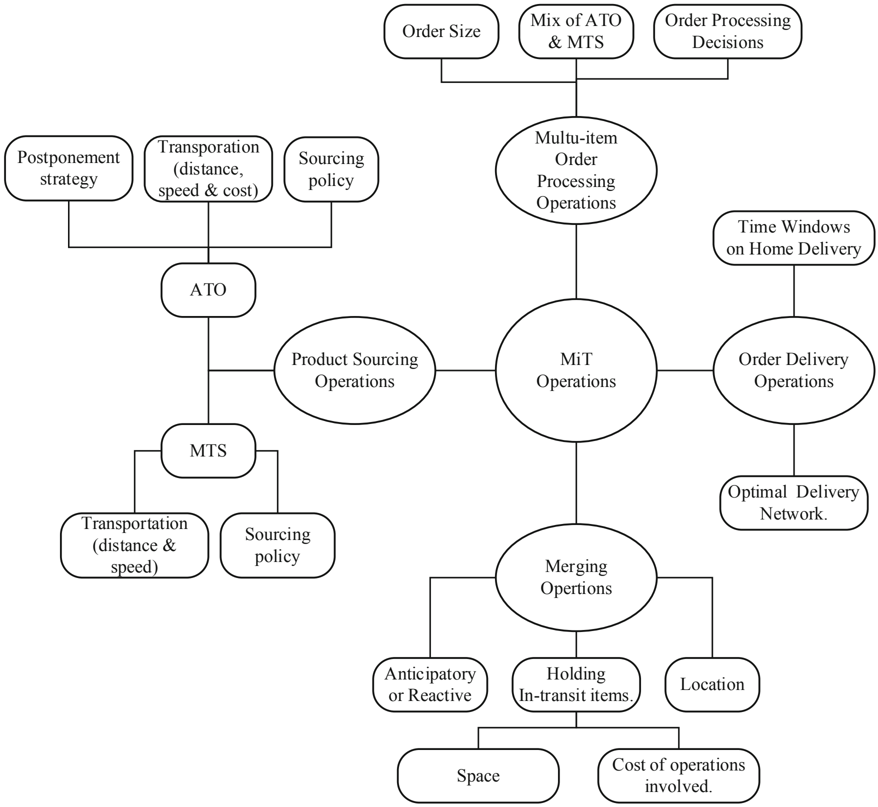

Fig. 3 Merge-in-transit operations

new technologies, given the aforementioned data constraints [15]. In addition, simulations—especially system dynamics simulations—facilitate capturing the dynamics of complex systems, which is the case of supply chain activities such as product delivery, where actions taken by one actor can impact the entire supply chain. For instance, levels of upstream, internal manufacturing and downstream complexity will have a negative impact on plant performance. Bozarth et al. [16] performed an empirical analysis, based on a sample of 209 plants from seven countries. The outcomes of the analysis support these complexity hypotheses. Three supply chain complexity drivers stand out in terms of their impact on performance: long supplier lead times, instability in the master production schedule, and variability in demand [16].

6 Complexity in Supply Chains and Agent-Based Simulation

Vachon and Klassen [17] showed that the complexity of the supply chain had an impact on delivery performance. In particular, strong statistical evidence was found for a relationship between delivery performance and both process technology complicatedness and management systems uncertainty. For instance, the recent trend toward outsourcing (less vertical integration) is very consistent with findings that reduced complexity can improve delivery performance. The simpler processes and greater specialization that result, likely coupled with increased flexibility, serve to improve this aspect of operational performance. Moreover, these results were consistent, regardless of the economic context and level of development that a particular firm faced [17].

As shown by Birkinshaw and Heywood [18], complexity kills supply chains. The main message for practice seems straightforward: simplify your supply chains (within the limits of your business model)! Birkinshaw and Heywood [18] also noted that: "Despite widespread agreement that organizational complexity creates big problems by making it hard to get things done, few executives have a realistic understanding of how complexity actually affects their own companies." In this respect, complexity is driven by observable supply chain characteristics such as the number of direct suppliers or the geographic distances between a focal firm and its suppliers. These results offer hints to managers about the aspects of supply chain design that lead to more disruption-prone supply chains. All three structural drivers of supply chain complexity amplify the frequency of disruptions, and decision-makers are well advised to be attentive to these aspects when they organize their supply chains. In other words, the study's insights assist practitioners in assessing the impact of supply chain management strategies, like outsourcing or supply base reduction, on the exposure to supply chain risk, but most importantly, hints the use of tools to reduce complexity in the supply chain [18].

Supply chain complexity increases as supply chains become more exposed to various sources of risk, and not since the end of World War II have supply chains been as exposed to risks as they are now [19]. Higher demand volatility, unprecedented technological changes, and supply chain speed intensify risk exposure. Again, this complexity lumps and reflects in the final stage of forward supply chain operations—product delivery. Managing this complexity requires visibility.

Visibility is one feature of supply chain management that helps improve supply chain performance, but it is not the only feature of supply chain management that could facilitate better performance. Also, the IoT is a technology tool to improve visibility through integration, but visibility may be attained by other means without IoT. Simulation supports the analysis, planning, and assessment of product deliveries and other supply chain activities by enabling the isolation of specific impacts stemming from different sources, such as enhanced visibility using the IoT or other means.

The use of models/simulations has a long history at some stages in the product life and has proved to be a helpful tool for reducing complexity. For instance, models and simulations of a real time cylinder testing system create and reproduce results that sufficiently represent the real world. The simplified model/simulation can be used to evaluate parts of the control before commissioning. In addition, the use of one simulation across all engineering teams facilitates communication in early stage product development that causes improvements in design efficiency and project management [20].

Simulation also provides improved process planning because it confirms feasibility, time analysis, and other considerations. This activity, now being an integral part of the entire process, facilitates having a faster and more flexible approach when resolving complex issues within the product delivery environment. The time from plan to execution has been reduced, and the actual execution duration has been reduced, which means that assets get higher utilization, which in turn creates a virtuous cycle helping to reduce product delivery time. This is especially important in make-to-order and customizable products, for instance, where there has been a reduced number of changes due to assembly issues. An added benefit is the reduced number of prototypes required for manufacturing. Simulation relays much more confidence to only build a few of those because of the improved work done during the design activities [21].

A different application of simulation for product delivery is assessing on-street parking strategies. Urban scenarios are extremely complicated for distribution for several reasons. The urban structure induces accessibility constraints and logistical efficiency problems. One of these reasons is a place to park the distribution vehicle. Although parking seems simple, it is a major factor for goods delivery. The parking problem results in the increase of trip delays, a lower reliability, and in some cases inefficient logistical systems by using more vehicles than necessary, which in turn increases the problem. Simulation helps to assess different scenarios, factors, and impacts of the parking issue. For instance, Boussier et al. [22] used simulation to evaluate consequences of interactions between different actors of transportation systems with their environmental benefits. Specifically, they "simulate the traffic and environmental consequences of several scenarios for different infrastructures, occupancy rate of the places reserved for goods delivery and durations of the delivery process" [22].

On-time delivery is one of the always-present challenges most industries face. Service is mostly measured by the ability to meet on-time deliveries. Nowadays, distribution operations move in fast-changing environments, and standard and static analysis cannot reflect the dynamics of these changes. On-time delivery becomes more challenging in businesses focused on home-delivery, such as the e-commerce industry [23].

Simulation many times entails a causal analysis to determine means to improve processes; however, evaluating causes also enables users to build and answer what-if scenarios and questions. This type of simulation analysis helps effective planning for different future possibilities, because it can easily and quickly show the consequences over time of changing any input assumption or parameter. What-if analysis measures how changes in a set of independent variables impact on a set of dependent variables with reference to a simulation model offering a simplified representation of the business, designed to display significant features of the business, and tuned according to the historical enterprise data [24]. Therefore, what-if simulation analysis can be used rapidly to explore a wide range of options and scenario changes. Thus, managers can use what-if analyses to anticipate the most likely future situations they will need to manage and then plan accordingly.

One simulation technique that has proven useful to real-world business problems such as product delivery is agent-based modeling (ABM). This simulation technique is typically focused on four areas or application: flow simulation, organization simulation, market simulation, and diffusion simulation [25].

ABM represents a system as a collection of autonomous decision-making entities known as agents. These agents carry out activities or tasks pertaining to the system they belong (e.g., producing, consuming, selling). The interactions between these agents are the main feature of agent-based modeling, which relies on the power of computers to explore dynamics impossible to attain by pure mathematical methods. The main advantages of ABM are its abilities to capture the results of these interactions, the description of complex system (such as systems compound by behavioral agents), and its flexibility.

Product delivery operations show features and requirements that may benefit from what-if simulation analysis and ABM techniques. Some of these features stem from the fact that product delivery is strongly influenced by demand, policy, infrastructure, fuel/energy prices, and transportation modes. In addition, the impacts of product delivery are significant in areas such as energy consumption and the environment.

Since one application area of ABM is flow simulation, within this area specific what-if questions on delivery flows may be addressed, such as:

- What if demand changes? Delivery is driven by end demand, which is extremely difficult to predict accurately. Reasons for this are data limitations and the complexity of the interacting factors that determine demand. ABM simulation may help supplementing demand uncertainty by providing flexible analysis in terms of impacts from different demand scenarios.
- What if policy changes? As with demand, the changes in policy and the impact of these changes are hard to visualize with clarity. Generally, policy translates into constraints for operations purposes. The ability to relax these constraints by changing operation practices is vital for mitigating unwanted effects in delivery flows. Once again, the simulation of these policy impacts, and the building of model scenarios on how to address them, may provide a sound base for planning.
- What if infrastructure changes? Infrastructure establishes the physical boundaries of delivery flows. Regardless of changes in policy and demand, infrastructure leaves no room for slack and is costly and time demanding. This type of hard, lengthy, and costly changes is where simulation may provide the most benefit. For instance, impacts from different routing scenarios reflecting infrastructure implementation, changes in infrastructure capacity, or changes in road network

structure in terms of links and nodes are just a few of the specific situations that could be evaluated through simulation.

Other what-if questions like fuel costs and combinations of transportation modes are highly regarded as important for delivery flows. Currently, fuel costs have a high variability and uncertainty, and they represent a large portion of the total delivery cost. This relates to the different transportation modes that are involved in product delivery. Supply chain managers attempt using and balancing multimodality to keep high costs at bay, while providing a high level of service. To achieve the right balance, many factors and actors need to be considered, as well as the relationships among these factors and actors. Simulation, and specifically ABM simulation, enables users to assess the dynamics of all these elements and produce balanced configurations for costs and multimodal operations.

Techniques such as ABM allow model building to be iterative. For instance, adding layers with some energy consumption or environmental (e.g., carbon-foot print) measures could simulate different energy-scenarios. Moreover, the resulting behavior can have properties that are decoupled from the properties of the parts (i.e., the agents). In other words, in ABM, each agent is modeled as an autonomous unit following specific rules; this allows predicting the emerging collective behavior. In addition, ABM not only helps in assessing time steady behavior, but also enables dealing with more complex individual behavior, including learning and adaptation [25].

As previously mentioned, enhanced visibility using the IoT or other means may be adequately analyzed by isolating specific effects or impacts stemming from agents' activities and capabilities, such as technology usage. The latter is of essence for planning and assessment of product deliveries and other supply chain activities.

7 Conclusion

Product delivery is an area where operations simulation can be an aid for evaluating coordination and performance assessment. Digitalization of information allows multiple information flows that make coordination of delivery supply chains very effective. In practical terms, last mile delivery has been subject to an extensive effort to improve customer satisfaction, not only in due date management and coordination but also the management of returns, drop off delivery windows, and optimal routing for parcel companies. Operation simulation with Industry 4.0 has a vital role in evaluating on-time delivery of products. Specifically, discrete event simulation is being used to evaluate due dates for made-to-order products that include many uncertainties. This variability can be evaluated in simulation scenarios were inventory conditions and replenishment policies can be evaluated not only for fulfilling customer expectations but also to make delivery operations at minimum cost. Discrete event simulation is an efficient tool for capturing all sources of variability, so it produces good time and cost estimates. The configurations on complex products with many combinations have been helped by big data analytics that are able to sort large amounts of combinations. These combinations can come from much data for product personalization to the complex combinations of a delivery vehicle scheduled to visit end-customers.

Computer simulation has the potential to deliver more solutions to the product delivery analysis; some areas with potential are the web-based simulation that can help in estimating lead times from product customization to the delivery at a customer's house. The further integration of manufacturing operations and design to the adding value activities in product delivery is an area under development for Enterprise Resource Planning providers. ABM is being used for the development of more detailed solutions.

References

1. Cruz-Mejia O, Marmolejo J, Vasant P (2018) Ambient Intell Human Comput 9:867. https://doi.org/10.1007/s12652-017-0577-2
2. Petersen CG, Aase G (2004) A comparison of picking, storage, and routing policies in manual order picking. Int J Prod Econ 92:11–19. https://doi.org/10.1016/j.ijpe.2003.09.006
3. Kung SH, Huang C, Kuo W (2011) Order picking algorithms for a two carousel-single-crane automated storage and retrieval system. J Inf Optim Sci 32(3):180–196
4. Barreto L, Amaral A, Pereira T (2017) Industry 4.0 implications in logistics: an overview. Procedia Manuf 13:1245–1252
5. Gobbo JA, Busso CM, Gobbo SC, Carreao H (2018) Making the links among environmental protection, process safety and industry 4.0. Process Saf Environ Prot 117:372–382. https://doi.org/10.1016/j.psep.2018.05.017
6. Smidfelt-Roskqvist L, Winslott-Hiselius L (2016) Online shopping habits and the potential for reductions in carbon dioxide emissions from passenger transport. J Clean Prod 131:163–169. https://doi.org/10.1016/j.jclepro.2016.05.054
7. Fu Y, Ding J, Wang H, Wang J (2018) Two-objective stochastic flow-shop scheduling with deteriorating and learning effect in Industry 4.0 based manufacturing system. Appl Soft Comput 68:847–855
8. Luque A, Estela Peralta M, De las Heras A, Cordoba A (2017) State of the industry 4.0 in the andalusian food sector. Procedia Manuf 13:1199–1205. https://doi.org/10.1016/j.promfg.2017.09.195
9. Miyatake K, Nemoto T, Nakahari S, Hayashi K (2016) Reduction in consumers' purchasing cost by online shopping. Tenerife, Elsevier, Canary Islands, Spain, vol. 12, pp. 656–666
10. Liu S, Zhang G, Want L (2018) IoT-enabled dynamic optimization for sustaniable reverse logistics. Proc CIRP 69:662–667. https://doi.org/10.1016/j.procir.2017.11.088 (Copenhagen, Denmark, Eslevier)
11. Calatayud A (2017*)* The connected supply chain: enhancing risk management in a changing world. Institutions for development sector connectivity, markets, and finance division. Inter-American Development Bank
12. Whitmore A, Agarwal A, Xu LD (2015) The internet of things—A survey of topics and trends. Inf Syst Front 17:261–274
13. Abazi B (2016) An approach to the impact of transformation from the traditional use of ICT to the internet of things: how smart solutions can transform SMEs. IFAC PapersOnLine 49(29):148–151
14. Yu J, Subramanian N, Ning K et al (2015) Product delivery service provider selection and customer satisfaction in the era of internet of things: a Chinese e-retailers' perspective. Int J Prod Econ 159:104–116

15. Sarac A, Absi N, Dauzère-Pérès S (2010) A literature review on the impact of RFID technologies on supply chain management. Int J Prod Econ 128(1):77–95
16. Bozarth CC, Warsing DP, Flynn BB et al (2009) The impact of supply chain complexity on manufacturing plant performance. J Oper Manag 27:78–93
17. Vachon S, Klassen RD (2002) An exploratory investigation of the effects of supply chain complexity on delivery performance. IEEE T Eng Manage 49:218–230
18. Birkinshaw J, Heywood S (2010) Putting organizational complexity in its place. McKinsey & Company. https://www.mckinsey.com/business-functions/organization/our-insights/putting-organizational-complexity-in-its-place
19. Christopher M, Holweg M (2017) Supply chain 2.0 revisited: a framework for managing volatility-induced risk in the supply chain. Int J Phys Distr Log 47:2–17
20. Pawlus W, Liland F, Nilsen N (2017) Modeling and simulation of a cylinder hoisting system for Real-Time Hardware-in-the-Loop testing. SPE drilling and completion 32:69–78
21. Venables M (2006) Better by design. Digital manufacturing. IET manufacturing engineer, 85(3):24–27
22. Boussier JM, Cucu T, Ion L et al (2011) Simulation of goods delivery process. Int J Phys Distr Log 41:913–930
23. Garcia ML, Centeno MA, Peiialoza, G (1999) A simulation of the product distribution in the newspaper industry. In: Proceedings of the 1999 winter simulation conference, vol. 2, pp 1268–1271
24. Golfarelli M, Rizzi S (2009) What-if Simulation Modeling in Business Intelligence. Int J Data Warehousing 5:24–43
25. Bonabeau E (2002) Agent-based modeling: methods and techniques for simulating human systems. Proc Nat Acad Sci 99:7280–7287

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M. M. Gunal (ed.), *Simulation for Industry 4.0*, Springer Series in Advanced Manufacturing, https://doi.org/10.1007/978-3-030-04137-3

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