

Alp Ustundag · Emre Cevikcan

Industry 4.0: Managing The Digital Transformation

 Springer

Preface

As a new industrial revolution, the term Industry 4.0 is one of the most popular topics among industry and academia in the world. Industry 4.0 plays a significant role in strategy to take the opportunities of digitalization of all stages of production and service systems. The fourth industrial revolution is realized by the combination of numerous physical and digital technologies such as artificial intelligence, cloud computing, adaptive robotics, augmented reality, additive manufacturing and Internet of Things (IoT). Regardless of the triggering technologies, the main purpose of industrial transformation is to increase the resource efficiency and productivity to increase the competitive power of the companies. The transformation era, which we are living in now, differs from the others in that it not only provides the change in main business processes but also reveals the concepts of smart and connected products by presenting service-driven business models.

In this context, this book is presented so as to provide a comprehensive guidance for Industry 4.0 applications. Therefore, this book not only introduces implementation aspects of Industry 4.0, but also proposes conceptual framework for Industry 4.0 with respect to its design principles. In addition, a maturity and readiness model is proposed so that the companies deciding to follow the path of digital transformation can evaluate themselves and overcome the problem of spotting the starting point. A technology roadmap is also presented to guide the managers of how to set the Industry 4.0 strategies, select the key technologies, determine the projects, construct the optimized project portfolio under risk and schedule the projects in planning horizon. Meanwhile, the reflections of digital transformation on engineering education and talent management are also discussed. Then, the book proceeds with key technological advances that form the pillars for Industry 4.0 and explores their potential technical and economic benefits via demonstrations with real-life applications.

We would like to thank all the authors for contributing to this book

- Sule Itir Satoglu, Istanbul Technical University
- Basar Oztaysi, Istanbul Technical University
- Sezi Cevik Onar, Istanbul Technical University

- Gokhan Ince, Istanbul Technical University
- Ihsan Kaya, Yildiz Technical University
- Erkan Isikli, Istanbul Technical University
- Gaye Karacay, Istanbul Technical University
- Burak Aydin, Silver Spring Networks
- Omer F. Beyca, Istanbul Technical University
- Mehmet Bulent Durmusoglu, Istanbul Technical University
- Seda Yanik, Istanbul Technical University
- Selcuk Cebi, Yildiz Technical University
- Gulsah Hancerliogullari, Istanbul Technical University
- Mehmet Serdar Kilinc, Oregon State University
- Mustafa Esengun, Istanbul Technical University
- Baris Bayram, Istanbul Technical University
- Ceren Oner, Istanbul Technical University
- Mahir Oner, Istanbul Technical University
- Beyzanur Cayir Ervural, Istanbul Technical University
- Bilal Ervural, Istanbul Technical University
- Peiman Alipour Sarvari, Istanbul Technical University
- Alperen Bal, Istanbul Technical University
- Aysenur Budak, Istanbul Technical University
- Cigdem Kadaifci, Istanbul Technical University
- Ibrahim Yazici, Istanbul Technical University
- Mahmut Sami Sivri, Istanbul Technical University
- Kartal Yagiz Akdil, Istanbul Technical University

We would also like to thank our colleague Ceren Salkin Oner for her support to prepare the final format of the book. And finally, we thank our families for their moral support and endless patience.

Istanbul
2017

Alp Ustundag
Emre Cevikcan

Contents

Part I Understanding Industry 4.0

1	A Conceptual Framework for Industry 4.0	3
	Ceren Salkin, Mahir Oner, Alp Ustundag and Emre Cevikcan	
1.1	Introduction	4
1.2	Main Concepts and Components of Industry 4.0	5
1.2.1	State of Art	6
1.2.2	Supportive Technologies	7
1.3	Proposed Framework for Industry 4.0	17
1.4	Conclusion	21
	References.	22
2	Smart and Connected Product Business Models	25
	Sezi Cevik Onar and Alp Ustundag	
2.1	Introduction	25
2.2	Business Models	26
2.3	Key Business Model Components of Smart and Connected Products	28
2.4	Proposed Framework	29
2.4.1	Value Proposition	29
2.4.2	IoT Value Creation Layers and Technologies	31
2.5	Conclusion and Further Suggestions	40
	References.	40
3	Lean Production Systems for Industry 4.0	43
	Sule Satoglu, Alp Ustundag, Emre Cevikcan and Mehmet Bulent Durmusoglu	
3.1	Introduction	43
3.2	Literature Review	45
3.3	The Proposed Methodology	47
3.4	Automation Based Lean Production Applications	53
3.5	Conclusion	56
	References.	57

4	Maturity and Readiness Model for Industry 4.0 Strategy	61
	Kartal Yagiz Akdil, Alp Ustundag and Emre Cevikcan	
4.1	Introduction	61
4.2	Existing Industry 4.0 Maturity and Readiness Models	63
4.2.1	IMPULS—Industrie 4.0 Readiness (2015).	63
4.2.2	Industry 4.0/Digital Operations Self-Assessment (2016)	65
4.2.3	The Connected Enterprise Maturity Model (2016).	66
4.2.4	Industry 4.0 Maturity Model (2016)	67
4.3	Comparison of Existing Industry 4.0 Maturity and Readiness Models	68
4.4	Proposed Industry 4.0 Maturity Model	68
4.5	An Application in Retail Sector	74
4.6	Conclusion	77
	Appendix: Survey Questionnaire	77
	References.	93
5	Technology Roadmap for Industry 4.0	95
	Peiman Alipour Sarvari, Alp Ustundag, Emre Cevikcan, Ihsan Kaya and Selcuk Cebi	
5.1	Introduction	95
5.2	Proposed Framework for Technology Roadmap	97
5.2.1	Strategy Phase	98
5.2.2	New Product and Process Development Phase	100
5.3	Conclusion	102
	References.	103
6	Project Portfolio Selection for the Digital Transformation Era	105
	Erkan Isikli, Seda Yanik, Emre Cevikcan and Alp Ustundag	
6.1	Introduction	106
6.2	Literature Review	107
6.3	Project Portfolio Optimization Model	111
6.4	Application	113
6.5	Conclusion	118
	References.	119
7	Talent Development for Industry 4.0	123
	Gaye Karacay	
7.1	Introduction	123
7.2	Skill Requirements in the Digital World.	126
7.3	Talent Development Practices for Industry 4.0	130
7.4	Conclusion	134
	References.	135

8 The Changing Role of Engineering Education in Industry 4.0 Era 137
 Sezi Cevik Onar, Alp Ustundag, Çigdem Kadaifci and Basar Oztaysi

8.1 Introduction 137

8.2 New Education Requirements. 139

 8.2.1 Education Content 139

 8.2.2 E-Learning Technologies. 141

 8.2.3 Working in Interdisciplinary Teams. 142

8.3 New Engineering Education Requirements and the Current Engineering Education 143

 8.3.1 Innovation/Entrepreneurship 144

 8.3.2 Data and Computing Technologies 145

 8.3.3 Value Added Automated Operations 146

8.4 Conclusion and Further Suggestions. 147

Appendix A 147

References. 151

Part II Technologies and Applications

9 Data Analytics in Manufacturing 155
 M. Sami Sivri and Basar Oztaysi

9.1 Introduction 155

9.2 Literature Review 156

 9.2.1 Power Consumption in Manufacturing 157

 9.2.2 Anomaly Detection in Air Conditioning 158

 9.2.3 Smart Remote Machinery Maintenance Systems with Komatsu 159

 9.2.4 Quality Prediction in Steel Manufacturing. 161

 9.2.5 Predicting Drilling Efficiency. 162

 9.2.6 Estimation of Manufacturing Cost of Jet Engine Components. 162

9.3 Methodology. 163

 9.3.1 Techniques Used for Predictive Analytics 164

 9.3.2 Forecast Accuracy Calculation. 166

9.4 A Real World Case Study 168

 9.4.1 Definition of the Problem 168

 9.4.2 Data Gathering and Cleaning. 168

 9.4.3 Model Application and Comparisons. 169

9.5 Conclusion 170

References. 171

10 Internet of Things and New Value Proposition 173
 Gaye Karacay and Burak Aydın

10.1 Introduction 173

10.2 Internet of Things (IoTs) 175

10.3	Examples for IoTs Value Creation in Different Industries.	177
10.3.1	Smart Agriculture	177
10.3.2	Smart City.	179
10.3.3	<i>Smart Life—Wearable Technologies</i>	180
10.3.4	Smart Health.	181
10.4	IoT Value Creation Barriers: Standards, Security and Privacy Concerns.	182
10.4.1	Privacy Concerns.	183
10.4.2	Standardization	183
10.5	Conclusion	183
	References.	185
11	Advances in Robotics in the Era of Industry 4.0	187
	Barış Bayram and Gökhan İnce	
11.1	Introduction	187
11.2	Recent Technological Components of Robots.	189
11.2.1	Advanced Sensor Technologies	189
11.2.2	Artificial Intelligence	191
11.2.3	Internet of Robotic Things.	191
11.2.4	Cloud Robotics	192
11.2.5	Cognitive Architecture for Cyber-Physical Robotics . . .	193
11.3	Industrial Robotic Applications.	194
11.3.1	Manufacturing	194
11.3.2	Maintenance	197
11.3.3	Assembly.	197
11.4	Conclusion	198
	References.	198
12	The Role of Augmented Reality in the Age of Industry 4.0	201
	Mustafa Esengün and Gökhan İnce	
12.1	Introduction	201
12.2	AR Hardware and Software Technology.	202
12.3	Industrial Applications of AR.	204
12.3.1	Maintenance	204
12.3.2	Assembly.	207
12.3.3	Collaborative Operations	208
12.3.4	Training.	210
12.4	Conclusion	212
	References.	213
13	Additive Manufacturing Technologies and Applications	217
	Omer Faruk Beyca, Gulsah Hancerliogullari and Ibrahim Yazici	
13.1	Introduction	218
13.2	Additive Manufacturing (AM) Technologies	218
13.2.1	Stereolithography.	219
13.2.2	3DP.	219

13.2.3	Fused Deposition Modeling	219
13.2.4	Selective Laser Sintering	220
13.2.5	Laminated Object Manufacturing.	220
13.2.6	Laser Engineered Net Shaping.	220
13.2.7	Advantages of Additive Manufacturing	220
13.2.8	Disadvantages of Additive Manufacturing	221
13.3	Application Areas of Additive Manufacturing	221
13.3.1	Medical	223
13.3.2	Surgical Planning	223
13.3.3	Implant and Tissue Designing	223
13.3.4	Medical Research	224
13.3.5	Automotive	224
13.3.6	Aerospace	225
13.3.7	Education	226
13.3.8	Biotechnology	227
13.3.9	Electronics.	228
13.3.10	Design	228
13.3.11	Oceanography	228
13.4	Impact of Additive Manufacturing Techniques on Society	229
13.4.1	Impact on Healthcare.	229
13.4.2	Impact on Environment.	229
13.4.3	Impact on Manufacturing and Supply Chain	230
13.5	Conclusion	230
	References.	231
14	Advances in Virtual Factory Research and Applications	235
	Alperen Bal and Sule I. Satoglu	
14.1	Introduction	236
14.2	The State of Art	238
14.2.1	Research Papers and Projects	238
14.2.2	The Virtual Factory Software	241
14.3	Limitations of the Commercial Software.	247
14.4	Conclusion	247
	References.	248
15	Digital Traceability Through Production Value Chain.	251
	Aysenur Budak, Alp Ustundag, Mehmet Serdar Kilinc and Emre Cevikcan	
15.1	Introduction	251
15.2	Digital Traceability Technologies	252
15.2.1	Architectural Framework	255
15.3	Applications	257
15.4	Project Management in Digital Traceability	260
15.5	Conclusion	263
	References.	263

- 16 Overview of Cyber Security in the Industry 4.0 Era 267**
 - Beyzanur Cayir Ervural and Bilal Ervural
 - 16.1 Introduction 267
 - 16.2 Security Threats and Vulnerabilities of IoT 270
 - 16.3 Industrial Challenges 273
 - 16.4 Evolution of Cyber Attacks 275
 - 16.5 Cases (Cyber-Attacks and Solutions) 276
 - 16.6 Strategic Principles of Cyber Security. 280
 - 16.7 Cyber Security Measures 280
 - 16.8 Conclusion 282
 - References. 283
- Index 285**

Authors and Contributors

About the Authors

Alp Ustundag is a full Professor at Industrial Engineering Department of Istanbul Technical University (ITU) and the head of RFID Research and Test Lab. He is also the coordinator of MSc. in Big Data and Business Analytics programme in ITU. He had been responsible for establishment of Technology Transfer and Commercialization Office of ITU as an advisor to the Rector. He worked in IT and finance industry from 2000 to 2004. He is also the General Manager of Navimod Business Intelligence Solutions (<http://navimod.com/>) located in ITU Technopark, which is a software company focusing on data analytics and business intelligence solutions. He has conducted a lot of research and consulting projects in RFID systems, logistics and supply chain management and data analytics for major Turkish companies. His current research interests include data analytics, supply chain and logistics management, industry 4.0, innovation and technology management. He has published many papers in international journals and presented various studies at national and international conferences.

Emre Cevikcan is currently an associate professor of Industrial Engineering Department in Istanbul Technical University. He received the B.S. degree in Industrial Engineering from Yıldız Technical University, the M.Sc. degree and Ph.D. degree in Industrial Engineering from Istanbul Technical University. He studied the scheduling of production systems for his Ph.D. dissertation. His research has so far focused on the design of production systems (assembly lines, production cells, etc.), lean production, scheduling. He has several research papers in International Journal of Production Research, Computers and Industrial Engineering, Assembly Automation, Expert Systems with Applications, International Journal of Information Technology & Decision Making. He is currently a reviewer in OMEGA, European Journal of Operational Research, International Journal of Production Research, Applied Soft Computing, Journal of Intelligent Manufacturing and Journal of Intelligent and Fuzzy Systems.

Contributors

Kartal Yagiz Akdil is a fresh Industrial Engineer and he is a business developer and R&D member in Migros Ticaret A.Ş. He is involved in many projects in the retail industry and led a specific project about gaming and e-sport. He is also the co-founder of Coinkolik (<http://coinkolik.com>) which is a Turkish news resource on bitcoin, blockchain and digital currencies. Previously, he co-founded FullSaaS, the

web-based directory focused on SaaS and cloud applications. Kartal received his B.S. in Industrial Engineering from Istanbul Technical University. Kartal speaks fluent Turkish and English.

Burak Aydin has a Mechanical Engineering degree from Middle Eastern Technical University followed by an MBA degree. He started his professional career working as a consultant at Andersen Consulting/Accenture in Germany and Austria offices between 2001–2003. He worked for Siemens Business Systems as a Strategic Planning Manager between 2003–2006. He joined Intel Corporation Turkey by 2006 and lead as Managing Director between 2011–2016, established Intel Turkey R&D Center on May 2014, focusing on Internet of Things (IoTs) technologies. By 2017, Burak Aydin joined Silver Spring Networks as a Europe Middle East and Africa (EMEA) General Manager.

Alperen Bal received the B.E. degree in Mechanical Engineering from Namik Kemal University, Tekirdag, in 2010, and M.Sc. degree in Industrial Engineering from Istanbul Technical University, Istanbul, in 2013 respectively. Since 2013, he has been a Ph.D. candidate in Industrial Engineering in Istanbul Technical University. His current research interest includes lean production systems and logistics and supply chain management.

Baris Bayram is a Ph.D. candidate in the Faculty of Computer and Informatics Engineering at Istanbul Technical University. He received his B.Sc. degree from Izmir University of Economics, and his M.Sc. degree from Istanbul Technical University. His major research interest is robot perception.

Omer Faruk Beyca received the B.S. degree in industrial engineering from Fatih University, Istanbul, Turkey, in 2007, and the Ph.D. degree from the School of Industrial engineering and Management, Oklahoma State University, Stillwater, OK, USA. He is currently an Assistant Professor with the Department of Industrial Engineering, Istanbul Technical University, Istanbul, Turkey. Prior to that, he was a faculty member with the Department of Industrial Engineering, Fatih University, Istanbul, Turkey. His current research interests are modeling nonlinear dynamic systems and quality improvement in micro-machining and additive manufacturing.

Aysenur Budak graduated from Industrial Engineering Department of Sabanci University in 2010. She got M.Sc. degree from Istanbul Technical University (ITU) in 2013 and continued her doctoral studies at the Department of Industrial Engineering of ITU, and currently she is a Research Assistant at ITU.

Selcuk Cebi is currently an Associated Professor of Industrial Engineering at Yildiz Technical University. He received degree of Ph.D. from Industrial Engineering Program of Istanbul Technical University in 2010 and degree of M.Sc. from Mechanical Engineering Department of Karadeniz Technical University in 2004. His current research interests are decision support systems, multiple-criteria decision-making, human–computer interactions, and interface design.

Mehmet Bulent Durmusoglu is a full Professor of Industrial Engineering at Istanbul Technical University. He obtained his Ph.D. in Industrial Engineering from the same university. His research interests are design and implementation of cellular/lean manufacturing systems. He has also authored numerous technical articles in these areas.

Beyzanur Cayir Ervural is a Research Assistant and Ph.D. candidate at Istanbul Technical University, Department of Industrial Engineering. Her major areas of interest include energy planning, forecasting, sustainability, multi-objective/criteria decision-making and optimization.

Bilal Ervural is a Ph.D. candidate and a Research Assistant at Industrial Engineering Department of Istanbul Technical University. His research interests include group decision-making, multiple-criteria decision-making, fuzzy logic applications, supply chain management, mathematical modelling and heuristic methods.

Mustafa Esengun studied computer engineering at the Middle East Technical University (METU) in Northern Cyprus (Turkey) and completed his M.Sc. at Computer Engineering Department of Istanbul Technical University (ITU). He is currently a research assistant at the Computer Engineering Department of ITU since 2014. His main academic interests are user experience of augmented reality interfaces and industrial applications of augmented reality technology. He is currently doing his Ph.D. on integrating AR solutions with industrial operations.

Gulsah Hancerliogullari is an assistant professor of Industrial Engineering at Istanbul Technical University. She graduated with B.S. and M.S. in Industrial Engineering, and a Ph.D. in Engineering Management and Systems Engineering. Her current research interests are empirical research in operations management, application of optimization methods to transportation and healthcare problems, inventory management and statistical decision-making.

Gokhan Ince received the B.S. degree in Electrical Engineering from Istanbul Technical University, Turkey, in 2004, the M.S. degree in Information Engineering in 2007 from Darmstadt University of Technology, Germany and the Ph.D. degree in the Department of Mechanical and Environmental Informatics, Tokyo Institute of Technology, Japan in 2011. From 2006 to 2008, he was a researcher with Honda Research Institute Europe, Offenbach, Germany and from 2008 to 2012, he was with Honda Research Institute Japan, Co., Ltd., Saitama, Japan. Since 2012, he has been an Assistant Professor with the Computer Engineering Department, Istanbul Technical University. His current research interests include human-computer interaction, robotics, artificial intelligence and signal processing. He is a member of IEEE, RAS, ISAI and ISCA.

Erkan Isikli is currently Lecturer of Industrial Engineering at Istanbul Technical University (ITU). He earned his B.Sc. in Mathematics Engineering from ITU,

Turkey, in 2004, and his Ph.D. in Industrial and Systems Engineering from Wayne State University, USA, in 2012. His research mainly focuses on “Product Variety Management” and “Statistical Modeling”. Along with his research activities, Dr. Isikli has taught courses on probability, statistics, stochastic processes, experimental design, quality control and customer relationship management.

Cigdem Kadaifci completed her Bachelor’s and Master’s degrees in Istanbul Technical University—Industrial Engineering Department. She has been working as a Research Assistant at the same department since 2010. She continues her Ph.D. in Industrial Engineering Programme and her research interests include futures research, multiple-criteria decision-making, statistical analysis and strategic management.

Ihsan Kaya received the B.S. and M.Sc. degrees in Industrial Engineering from Selçuk University. He also received Ph.D. degree from Istanbul Technical University on Industrial Engineering. Dr. Kaya is currently an Assistant Professor Dr. at Yıldız Technical University Department of Industrial Engineering. His main research areas are process capability analysis, quality management and control, statistical and multiple-criteria decision-making, and fuzzy sets applications.

Gaye Karacay is an Assistant Professor at the Industrial Engineering Department of Istanbul Technical University. Her Ph.D. in Management and Organization is from Bogazici University with a focus on Organizational Behaviour. Before her Ph.D. studies, Dr. Karacay had a professional work experience at public and private sector institutions in strategic management and public management areas. She has an MBA degree from London Business School (LBS). Her research interests include leadership, cross-cultural management, organizational culture, human resource management, talent management and corporate entrepreneurship. She has publications in international journals including Journal of World Business and Personnel Review. She has presented her studies at several international conferences.

Mehmet Serdar Kilinc is a postdoctoral researcher at Oregon State University. He formerly worked as a postdoctoral researcher at the Pennsylvania State University. He obtained his Ph.D. degree in industrial engineering at the University of Arkansas. He graduated with bachelor’s and master’s degrees from Istanbul Technical University, Turkey. His primary research interest is developing quantitative approaches to design and evaluate healthcare delivery and IT systems.

Ceren Oner received her B.S. degree in Industrial Engineering Department from Çukurova University in 2011. In 2011, she started to work as a Research Assistant in Istanbul Technical University and is currently a Ph.D. candidate in the same university. She writes and presents widely on issues of location-based systems, data mining and fuzzy logic.

Mahir Oner received his B.S. degree from Istanbul Technical University, Industrial Engineering Department. He had experience in private sector as business development engineer, method engineering and planning engineer. Currently, he is working as a research assistant in Istanbul Technical University and he is a Ph.D. candidate in the same university. His main research areas are real time tracking systems, RFID and Industry 4.0 applications.

Sezi Cevik Onar is an Associate Professor in the Industrial Engineering Department of Istanbul Technical University (ITU) Management Faculty. She earned her B.Sc. in Industrial Engineering and M.Sc. in Engineering Management, both from ITU. She completed her Ph.D. studies at ITU and visited Copenhagen Business School and Eindhoven Technical University during these studies. Her Ph.D. was on strategic options. Her research interests include strategic management and multiple criteria decision-making. She took part as a researcher in many privately and publicly funded projects such as intelligent system design, organization design, and human resource management system design. Her refereed articles have appeared in a variety of journals including Supply Chain Management: An International Journal, Computers & Industrial Engineering, Energy, and Expert Systems with Applications.

Basar Oztaysi is a full-time Associate Professor at Industrial Engineering Department of Istanbul Technical University (ITU). He teaches courses on data management, information systems management and business intelligence and decision support systems. His research interests include multiple criteria decision-making, data mining and intelligent systems.

Peiman Alipour Sarvari is a researcher at Industrial Engineering department of Istanbul Technical University. His current fields of interest include machine learning, virtual experiments, data analytics, supply chain management and logistics. He has plenty of book chapters and papers on maritime safety simulation, frequent pattern mining, artificial intelligence and mathematical inferences.

Sule Itir Satoglu is Associate Professor at Industrial Engineering Department of Istanbul Technical University (ITU). She earned her Mechanical Engineering bachelor's degree from Yildiz Technical University, in 2000. Later, she earned her Engineering Management M.Sc. degree in 2002, and Industrial Engineering Ph.D. degree in 2008, from Istanbul Technical University. Her research interests include lean production systems and logistics and supply chain management.

Mahmut Sami Sivri is currently a Ph.D. Candidate at Industrial Engineering Department in Istanbul Technical University. He also received the B.S. degree in Computer Engineering and the M.Sc. degree in Engineering Management from Istanbul Technical University. He worked in various companies and positions in the software industry since 2008. His current research interests include big data and applications, Industry 4.0, financial technologies, data analytics, supply chain and logistics optimization as well as software development and web applications.

Seda Yanik is an associate professor in Istanbul Technical University (ITU), Department of Industrial Engineering. She earned both her B.Sc. (1999) and Ph.D. (2011) degrees in Industrial Engineering from ITU. She also worked at multinational companies, such as SAP and adidas. Her research areas include logistics and supply chain, location modelling, decision-making and statistical quality control. She has published many papers in top-tier journals such as European Journal of Operations Research, Knowledge-Based Systems, and Network and Spatial Economics.

Ibrahim Yazici has been research assistant for 5 years. He is doing Ph.D in industrial engineering at Istanbul Technical University. He received B.Sc. degree in Industrial Engineering from Kocaeli University in 2011, M.Sc. degree from ITU in 2015. His interest areas are multiple-criteria decision-making, data mining applications, business analytics.