Jack C Chaplin · Claudia Pagano
Santi Fort *Editors*

Digital Manufacturing for SMEs

An Introduction

Digit-T
DIGITAL MANUFACTURING TRAINING

Editors

Jack C Chaplin
Institute for Advanced Manufacturing
University of Nottingham
Nottingham
UK

Claudia Pagano
Institute of Intelligent Industrial Technologies
and Systems for Advanced Manufacturing
National Research Council
Milan
Italy

Santi Fort
Eurecat
Barcelona
Spain

Co-funded by the
Erasmus+ Programme
of the European Union

ISBN: 978-0-85358-339-4

Preface

The manufacturing industry is currently witnessing a transformation as it increasingly moves towards Digital Manufacturing - often known as Industry 4.0, Smart Manufacturing and Factory of the Future. It offers opportunities for companies to develop new products and ways of working while reducing costs. However, many people and organisations, in particular SMEs, struggle to access clear and useful information about Digital Manufacturing.

This book aims to provide SMEs and other users with an introduction to digital manufacturing. It has been compiled by experts who are members of the consortium of the ERASMUS+ project Digit-T: Digital Manufacturing Training System for SMEs (2017-1-UK01-KA202-036807). This includes University of Nottingham, Institute of Intelligent Industrial Technologies and Systems for Advanced Manufacturing (STIIMA-CNR), EURECAT and AFIL.

This book collates contributions from within the field of digital manufacturing, and complements a free online training course developed by the Digit-T consortium which can be found at https://training.digit-t.eu/.

This book is divided into 3 parts.

Part I: Management in Industry 4.0 aims to provide a basic understanding of the concepts, trends and key technologies that characterise Industry 4.0. In addition it considers the roadmapping process which can support a company in prioritising and planning its own digital transformation. Finally, consideration is given to the impact of Industry 4.0 in human resource management, discussing the evolution and "buy-in" required in the work force, both leaders and employees, which is essential for a company to successfully move to a "Smart Factory".

Part II: Manufacturing Systems introduces the concepts of manufacturing analysis and decision making and breaks them down into formal processes which can be followed. It starts by introducing conventional decision making – methods for analysing manufacturing systems and networks to calculate key performance indicators or to identify areas of concern. The limitations of these methods are discussed before moving to discuss modern methods for manufacturing systems analysis, using offline modelling and simulation and state-of-the-art integrated digital twins and decision support systems.

Part III: Intelligent Robotics starts by explaining robotics generally, the different types of robots which exist, and providing a simple introduction to robot terminology, their different structures, their components and applications. The impact of Industry 4.0 in robotics is then considered and includes discussions on Cyber Physical Systems, collaborative robots which support human-robot collaboration, microrobotics and mobile robots. Finally, Artificial Intelligence and ethical issues associated with autonomous systems is considered.

This book is designed to be of interest to managers, engineers, researchers, students and lay people either operating or having interest in the manufacturing sector and who wish to gain a general understanding of the area of digital manufacturing and Industry 4.0. We hope we have achieved this goal.

Nottingham, UK — Jack C Chaplin
Milan, Italy — Claudia Pagano
Barcelona, Spain — Santi Fort

Contents

Part I Management in Industry 4.0

1 **Fundamental Concepts of Industry 4.0** 5

2 **Strategic Implementation** 27

3 **People and the Centre of I4.0** 61

Part II Manufacturing Systems

1 **Manufacturing Systems Analysis** 83

2 **Digital Modelling and Simulation of Manufacturing Systems** 125

3 **Digital Twins and Intelligent Decision Making** 159

Part III Intelligent Robotics

1 **Industrial Robots 4.0** 191

2 **Robotic Components** 213

3 **Industry 4.0 in Robotics** 231

Acronyms

1D	One Dimensional
2D	Two Dimensional
3D	Three Dimensional
5D	Seiri (Sort), Seiton (Set in Order), Seiso (Shine), Seiketsu (Standardise) and Shitsuke (Self-Discipline)
5G	Fifth generation cellular protocols
6LowPAN	Internet Protocol version 6 over Low-Power Wireless Personal Area Networks
AC	Alternating Current
ADKAR	Awareness, Desire, Knowledge, Action, Refinement
AGV	Automated Guided Vehicle
AHP	Analytical Hierarchy Process
AI	Artificial Intelligence
AIDC	Automatic Identification and Data Capture
AMM	Assemble-Measure-Move
ANN	Artificial Neural Network
ANSI	American National Standard Institute
API	Application Programming Interface
AR	Augmented Reality
AS/EN	Aerospace Standard / European Standard
ASME	American Society of Mechanical Engineers
B2C	Business to Consumer
BI	Business Intelligence
CAD	Computer Aided Design
CAE	Computer Aided Engineering
CAM	Computer Aided Manufacturing
CAN	Controller Area Network
CAPP	Computer Aided Process Planning
CAT	Computer Aided Tolerancing
CD-DSS	Communications-Driven Decision Support System
CDO	Chief Digital Officer
CEN	European Committee for Standardization

CENELEC	European Committee for Electrotechnical Standardization
CEO	Chief Executive Officer
CFRP	Carbon Fiber Reinforced Plastic
CIA	Confidentiality, Integrity and Availability
CL	Centreline of a control chart
CMM	Coordinate Measurement Machine
CMR	Crawler Mobile Robot
CNC	Computer Numerical Control
Cobot	Collaborative Robot
CPDMS	Capacitive PolyDiMethylSiloxane
CPS	Cyber Physical System
CRCPS	Collaborative Robotics Cyber-Physical Systems
CRM	Customer Relationship Management
CSV	Comma Separated Values
DAM	Decision Analysis Models
DBMS	Database Management System
DD-DSS	Data-Driven Decision Support System
DDS	Data Distribution Service
DES	Discrete Event Simulation
DfA	Design for Assembly
DfM	Design for Manufacture
DIS	Draft International Standard
DKIW	Data, Information, Knowledge, Wisdom
DMAIC	Define, Measure, Analyse, Improve, Control
DMS	Dedicated Manufacturing System
DOF	Degree(s) of Freedom
DSS	Decision Support System
EAS	Evolvable Assembly System
EASA	European Aviation Safety Agency
EBITDA	Earnings before Interest, Taxes, Depreciation, and Amortisation
EMC	Electromagnetic Compatibility
EN	Issued by CEN
ERP	Enterprise Resource Planning
ESB	Enterprise Service Bus
EtherCAT	Ethernet for Control Automation Technology
ETL	Extract, Transform, Load
Euro NCAP	European New Car Assessment Programme
FDM	Fused Deposition Modelling
FIFO	First In, First Out
FMS	Flexible Manufacturing System
GA	Genetic Algorithm
Gbps	Gigabits per second
GDPR	General Data Protection Regulation
GFSi	Global Food Safety Initiative

GHz	Gigahertz
GMAW	Gas Metal Arc Welding
GTAW	Gas Tungsten Arc Welding
HANA	HAsso's New Architecture
HMI	Human-Machine Interface
HRC	Human-Robot Cooperation
Hz	Hertz (frequency)
I4.0	Industry 4.0
ICT	Information and Communications Technology
ICY	Interchangeability
ID	Identifier
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IFR	International Federation of Robotics
IIC	Industrial Internet Consortium
IIoT	Industrial Internet of Things
IMU	Inertial measurement Unit
IoT	Internet of Things
IP	Internet Protocol
IP67	Ingress Protection code 67
Ipv6	Internet Protocol version 6
IR	InfraRed
ISO	International Organization for Standardization
JSON	JavaScript Object Notation
JTC	Joint Technical Committee
kbps	Kilobits per second
KD-DSS	Knowledge-Driven Decision Support System
KNIME	Konstanz Information Miner
KPI	Key Performance Indicator
LAN	Local Area Network
LCL	Lower Control Limit of a control chart
LED	Light-Emitting Diode
LIFO	Last In, First Out
LMR	Legged Mobile Robot
LMS	Learning Management System
LWR	Light Weight Robot
M2M	Machine to Machine
MAA	Measurement / Metrology-Assisted Assembly
MADA	Measurement-Assisted Determinate Assembly
MAG	Metal Active Gas welding
MAST	Manufacturing Agent Simulation Tool
MCS	Monte Carlo Simulation
MD-DSS	Model-Driven Decision Support System
MEMS	Micro-Electrical-Mechanical Systems

MES	Manufacturing Execution System
MESA	Manufacturing Enterprise Solutions Association
MHS	Material Handling System
MHz	Megahertz
MIG	Metal Inert Gas welding
ML	Machine Learning
MQTT	MQ Telemetry Transport
MTBF	MTBF: Mean Time Between Failure
NASA	National Aeronautics and Space Administration of the United States of America
NoSQL	Not Only Structured Query Language
NP	Nondeterministic Polynomial Time
NPI	New Product Introduction
OCR	Optical Character Recognition
OEE	Overall Equipment Effectiveness
OMG	Object Management Group
OPC UA	Open Platform Communications – Unified Architecture
OT	Operational Technologies
PAM	Pneumatic Air Muscles
PCA	Principal Component Analysis
PCDA	Plan, Do, Check, Act
PD	Proportional Derivative
PDA	Personal Digital Assistant
PESTLE	Political, Economic, Sociological, Technological, Legal and Environmental
PI	Proportional Integral
PID	Proportional Integral Derivative
PL	Performance Level
PLC	Programmable Logic Controller
PLM	Product Lifecycle Management
PN	Petri Nets
POS	Point of Sale
Profibus	Process Field Bus
PROFINET	Process Field Net
PSO	Particle Swarm Optimisation
PZT	Lead zirconate titanate
QN	Queueing Network
R&D	Research and Development
RCC	Remote Center of Compliance
RFID	Radio Frequency Identification.
RIA	Robotic Industries Association (US)
RL-DSS	Reciprocal Learning-Based Decision Support System
RMS	Reconfigurable Manufacturing System
ROCE	Return on Capital Employed Ratio

RoHS	Restriction of Hazardous Substances
ROI	Return on Investment
ROS	Robot Operating System
S3	Simple Storage Service
SA	Simulated Annealing
SaaS	Software as a Service
SAP	A software corporation specialising in enterprise support software
SC	Subcommittee
SCADA	Supervisory Control And Data Acquisition
SCARA	Selective Compliance Assembly Robot Arm
SCM	Supply Chain Management
SD	System Dynamics
SDK	Software Development Kit
SEM	Search Engine Marketing
SEO	Search Engine Optimization
SMA	Shape-Memory Alloy
SMAC	Social, Mobile, Analytics and Cloud
SME	Small and Medium size Enterprise
SPC	Statistical Process Control
SQC	Statistical Quality Control
SQL	Structured Query Language
SRP/CSs	Safety related Parts of Control Systems
SWOT	Strengths, Weaknesses, Opportunities and Threats
TC	Technical Committee
TCP	Tool Centre Point
TIG	Tungsten Inert Gas welding
TQM	Total Quality Management
TR	Technical Report
TS	Technical Specification
UCL	Upper Control Limit
USB	Universal Serial Bus
USD	United States Dollar
UX/UI	User Experience/User Interface
VR	Virtual Reality
WIP	Work in Progress
WMR	Wheeled mobile robot
WPPF	Whole-Part Predictive Fettling
WSN	Wireless Sensor Network
XML	eXtensible Mark-up Language