Conclusions and Outlook

The networkable device of the smart distributed manufacturing unit with mobile properties, working on the base of new principles, strongly informatising and decentralising manufacturing, has definitely stepped into the shopfloor to stay. Evolving network decision procedures, fully accepting the network nature of manufacturing, will replace the conventional, time slicing, command and control, one-time static, machine centred planning and control approaches as still mostly implemented in production control and enterprise resource planning. Fully incorporating network principles and, thus, making use of the network nature of manufacturing are the preconditions to overcome the particularities of high-frequency planning effects, as resource over-consumption and organisational hectic on the shopfloors. Cyber Physical Production Systems and the Internet of things challenge machines and equipment to become online, interconnected and interactive, which is fundamentally different from batch oriented logic of numerical control (NC) or Flexible Manufacturing Systems (FMS). More and better data will not cause more hectic, more frequent changes or more staccato revised decisions; accurate real-time data will rather install and maintain resource efficient, steady and smooth, easily manageable manufacturing progress, and enable to add more value in shorter time with far less input. First examples of implementing these principles already demonstrate astonishing results, and this is only the start. Witnessing the big players from telecommunication, hardware producers, software designers, and systems providers, and the huge innovation power behind, gives an impression that there will be intriguing novelties ahead in all branches. In distributed manufacturing, we are just at the beginning of an era of smart devices in all sectors; there might soon come up smart DM solutions, which we cannot even imagine today.

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Which Essentials Does the Book Cover?

With comprehensive description of this new working field, the book proposes solid ground to distributed manufacturing as a newly emerging discipline. This discipline will certainly live from outside contributions, theories from other areas and accentuated impacts of networking. Irrefutable evidence and motivation for interdisciplinary interaction are elaborated in Chap. 3, where the backgrounds of philosophy of sciences give important sidelines for the design of frameworks. Strong interactions between disciplines are instigated, not just limited to borrowing from outside but to changing and extending the core of the manufacturing field. By the topological construct of the Hausdorff space, a comprehensive and powerful frame is suggested as a base. This frame has already been an important tool for substantial work since 10 years, initially for fractalising factory network set-ups and for advanced models and procedures in collaborative facilities planning and process implementations; actually, this approach gets full support by the most recent developments around the Internet of Things and the Cyber Physical Systems in general as well as in the context of Distributed Manufacturing.

As the core of the set-up, a generic construct is proposed, using six layers, which catalyses interactions and interchanges between disciplines and, at the same time, preserves disciplines' aspects throughout the entire network on all levels of detail. Important attached models are introduced, especially in the demand, resource and decision-making context, and tied together by a decision space model, fully incorporating the criticality thinking from (neuro-)network sciences into manufacturing. Moreover, complexity, criticality and simultaneity establish manufacturing specific concurrency principles, synthesising the network levels of detail, and decision modes with network and process configuration issues. Key portions are immediate outcomes of applications of topological spaces, their fractal dimensions along with their patterns of self similarity. At this point, the full embedding of the established model worlds from manufacturing and manufacturing management, already known as the bases of enterprise software solutions, smoothly bridges from conventional manufacturing set-ups to the world of smart Distributed Manufacturing. As decision structures have to be considered key components in any manufacturing setup, an upcoming way of hybrid decision making is outlined in detail. Manufacturing units will exhibit additional properties to become part of smart Distributed Manufacturing networks in the defined sense. To meet the evolving character of these properties and their smartness, a Distributed Manufacturing Maturity Model (D3M) is proposed for evaluating technological readiness levels and smartness' achievements.

All instruments, set ups and models are embedded into significant and profoundly discussed Distributed Manufacturing implementation examples. The value of these examples in Chap. 6 is threefold, as they provide for:

- Verifications of all given theory portions and generic models, including the concurrency principles and the embedding of conventional model worlds

- Solid demonstrations of the suggested network decision mode as being iterative, gradual and levelled, exhibiting criticality thinking and fold/unfold mechanisms
- Irrefutable testimonials for the enormous power of smart distributed manufacturing implementations, underpinned by hard fact evidence of shifts in KPIs and future improvement potential.

Moreover, developments in further converging technology fields towards distributed manufacturing are anticipated in this outlook chapter.

What is the Value of the Book?

The book proposes the first comprehensive theory framework that treats manufacturing as distributed networks. The topological mapping, as introduced, easily succeeds in including the network nature of manufacturing processes from the basics. Less functional, less restricted, organisationally lower bounded and free from habitual domains, the approach also deeply incorporates a number of novel network possibilities into Distributed Manufacturing management and control. Abilities for comparing plans to real-time monitored process states unearths so far unseen potential for optimising resources' input and process efficiencies. The proposed decision cycle, the use of the concurrency principles, and the criticality thinking with the toolboxes offered allow the implementation of new procedures for control and management, which prove to more stable, come closer to the real events and which are, at the same time, simpler and more effective. Thereby, easy ways towards the next generation network resource planning are demonstrated for making full use of the smart units' properties and the Real Time Enterprise (RTE).

Manufacturing equipment producers and machine toolmakers find a comprehensive picture for mirroring their reconsiderations of design activities; they may take out orientation on the consequences, the risks, the market opportunities and innovation options for value creation with all involved objects co-operating online and interconnected. On top of all the excellent features and capabilities, modern manufacturing units and production equipment exhibits already, the units will unlock a variety of helpful IoT services that are increasingly promoted by external service providers. Continuous rethinking of all value chains and organisational set ups will become irrefutable permanent tasks for company planners and strategists. They will find both, profound discussions of the upcoming properties of manufacturing equipment, and demonstrations of the game changing rules in manufacturing networks. Company innovators will find valuable hints and proposals to verify their work and for taking their next steps on more stable decision grounds.

For shopfloor practitioners and system developers, sound descriptions of application examples are given. These examples are deliberately taken from a variety of distributed manufacturing implementations, displaying cloud computing, item localisation and ordertracking in chemical industries on one side, and smart extensions of advanced implementations in metal processing and auto supplier industry on the other.

Researchers find consolidated ground for further work in many directions; solid scientific base grants well-staked research fields; the roots of manufacturing are fully kept in mind while the network nature of manufacturing processes is acknowledged, an inevitable move for completely exploiting the Distributed Manufacturing's smart options. A framework for the field of Distributed Manufacturing including the interdisciplinary contributions for promising theory building is given as starting point for further research. The Hausdorff space, much earlier proposed and verified as suitable formal model for advanced manufacturing concepts by the authors already, obviously finds its practical translations in these days, e.g. as the cyber physical production system or smart object. The mappings, exhibited there, are technically realised by virtualisations of objects and units e.g. implemented as virtual machines (VM) into manufacturing equipment. Moreover, the framework provides adequate instruments for capturing complexity and variety, as desired. Fast progress in fragmentations and atomization of process steps and miniaturisation of technologies urged for more comprehensive, formal descriptions of units and process fragments, and better design to hold the networks together. The compounds are simple and, put together in the right way, at the same time, rich enough to cover all relevant manufacturing aspects in their full ranges.

For scholars and academics, the value of the book is manifold. There are sections, treating structuring and realigning manufacturing networks on one hand, and sections for reconsidering manufacturing units' smartness and decision models for planning, control and optimisation on the other. Factory centred thinking will be replaced; network guided views change all well-known models' roles. For the first time, a coherent approach for unfolding manufacturing networks into levels of details is proposed. This is only possible by reclassifying models into adequate sets, as visualised, and their consolidation according to standardised levels of detail. Moreover, with the Distributed Manufacturing Maturity Model, another visualising tool is made available.

Lecturers find a framework that incorporates complexity thinking, network view, structures to capture contributions from outside disciplines, and a setup for network management and control into manufacturing on coherent theory base. The theory set up is capable to do both, embedding conventional manufacturing solution spaces with the models used there, and flooring the new fields coming in with the novel devices and progresses in information technology in general. As a number of disciplines are involved, clusters of preferred disciplines are suggested for fertile integration in the case example discussions. For encouraging and facilitating interdisciplinary study work, a catchy layer construct is proposed. Pathways are paved for instigated interdisciplinary interactions right from the core, able to speed up both, project implementations and study work. Moreover, exhaustive examples, unifying the established models with novel procedure for manufacturing network evolution, are detailed and discussed. The book is kept free from formalisms and mathematical notation to make it accessible for practitioners and manufacturing students. The outline smoothly bridges existent solutions and the rapidly spreading new thinking. It also gives valuable support for training staffs in specialised manufacturing areas and grants easy and structured access to this rapidly emerging manufacturing network world.

Looking Ahead!

From what is already known about networking of enterprises will now be observed on lower levels of detail as well. Networked machines, equipment and parts will even be found on the field control level in the context of flexible manufacturing units and material. Collaboration of cyber existence, Internet of things and World Wide Web may certainly be addressed as the key enablers to shape real time enterprises. Pervasive computing has been one of the triggers of distributed manufacturing in just some areas. There is certainly much more to come, especially if the imagine embedded processors in practically every object and equipment. Mechanisms can be imagined for virtually composing products of intelligent components finding each other on the path of value creation; this option has not been addressed in advanced manufacturing concepts so far.

The huge potential of Distributed Manufacturing appears evident in a single company or factory already, whereas it is the option for multi site and multinational value and supply chains with most gains. Highly flexible and versatile structures may be exploited in global dimension most effectively; following this projection, entire manufacturing sectors may soon come up with overall resource sharing implementations, driven by remote cloud manufacturing (RCM) as well as higher integration of the product design process into Distributed Manufacturing, the Cloud-Based Design and Manufacturing (CBDM).

Another strongly upcoming field will be empowered machine to machine M2M communication; novel interaction modes concerning person to machine P2M are on the way. Smart technologies provide collaborative environments promoting adaptive agility, transparency and empowerment through more effectiveness. These environments easily outpower conventional setups, since everything is mobile and wireless and literally every feature is topped at scale. Waiting with implementation means obsolescence and decaying competitiveness!

Increasing portions of manufacturing will become information; optimisation of resource consumption will instigate the reuse of materials and promote the after-use of products. The term Distributed Manufacturing comprises the distribution of integrated resources as well as the integration of distributed resources; encapsulations of resources, units and object's models may be increasingly seen as parts of the cloud. All companies are facing ever-growing data volumes and computer power requirements, therefore cloud computing and big data shake up the service- and the outsourcing business; third parties will offer "Anything as a Service" (AaaS) as commodities on demand, scalable and always on the latest standards. This will again make manufacturing companies more dependent on IT providers. After visible reluctance of the leading software vendors to deal with novel technologies, meanwhile all cutting-edge players are fully involved leaving few alternatives to the competitors.

Wireless technologies have also brought direct telecommunications' involvement into manufacturing; this involvement is strongly gaining ground e.g. by efficient tracking systems, GPS positioning, smart metering, and wireless body area networks

(WBAN). Manufacturers of computer hardware as well as software vendors will have to take into account these developments and the revolutionising consequences thereof.

By definition, we include additive manufacturing to the context of Distributed Manufacturing, without further mentioning solutions or emphasising this technology in theory and examples. As far as the theory is concerned, additive manufacturing units may be smart units as any other unit, as described. Standard triangulation language STL may be emulated as any other control compound. The attention, additive manufacturing receives in recent studies, will certainly accelerate developments in the direction of shortening or eliminating process chains by more condensed information. Smart materials or materials with so far unseen attributes will open new horizons as e.g. zirconium ceramics or normal fibre materials. This is no contradiction, rather the full endorsement to our approach, magnifying the scope of Distributed Manufacturing by more options of design anywhere manufacture anywhere (DAMA). One of the key drivers, here again, is the Internet of things with the globally networked smart manufacturing unit.

We often discuss questions around what the future might bring for Distributed Manufacturing and smart automation; smartness of devices and its online awareness trigger peoples' imagination and fantasy, instantly evoking ideas and trajectories that could grasp future developments. Most experts agree that Moore's Law will still be valid for some time, so micro devices will gain enormous capabilities and will strongly promote progressing modularity of equipment and machines, so e.g. robots could adapt to literally every task by orchestrasting directly interacting smart modules. A crucial precondition is powerful M2M communication, which is broadly on the way. Furthermore, the rising impact of artificial intelligence (AI) is often pointed at. It is exactly here, where we see the highest potential, as the outdated top-down approach for modelling brain functions is being substituted by decentralised bottom-up mechanisms based on networks. Hebb's rule, highlighting "trial, error and incentive", may directly be applied as outcome of the concurrency principles in Chap. 4. The criticality thinking, introduced here, originates from network sciences and, indeed, neuro-scientific models of the human brain. Times are near, where smart machines will be more apt to do manufacturing tasks than humans will, at least for certain things, but specific abilities will surely remain genuine human domains. Rather than man versus machine scenarios, we see the smooth symbiotic mergence of the two, for highly sophisticated tasks' execution; a first important step in this direction is made by fully incorporating hybrid decision-making; here, we see a growing field that further fertilises all upcoming distributed manufacturing developments.

Both, product designs and equipment designs will rapidly progress. In the convergence of different technologies and disciplines we are only at the beginning of an era. Even though, the addressed technologies plus surely additional ones, merging nanotechnology and cognition sciences, exponentiating by information networks will surely bring about many more intriguing innovations, unexpected additional applications and astonishing novel solutions in manufacturing; the proposed theory approach is supposed to be ample enough to capture them all.

With this book, the proposed framework, the outlined theory approach with verifying instructive case studies, we strongly feel to step into the right direction and to speed up further developments on this fascinating research field of Distributed Manufacturing.

Annex

Fractals and Self Similarity

An object is considered to be self-similar if it looks about the same on any scale. **Fractals** are a particularly interesting class of self-similar objects. Self-similar objects with parameters described by a power law, such as $N = S^d$ where $d = \frac{\ln N}{\ln s}$ is the dimension of the scaling, are called fractals. It is also known as the Hausdorff dimension. Fractals play a decisive role in mastering complexity, as applied in organisation and factory operations as well. This view enables the introduction of self organisation, self optimisation and self structuring into or factory organisations. As this outline proves, the view can be extended into decision and aspect constructs.

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Topological Hausdorff Space

Be X an arbitrary set. As set of subsets of X ∈ T is named a Topology on X, if:
(1) X ∈ T
(2) every joint of the set of T is included in T
(3) finite intersections of sets of T are included in T,
so the pair (X; T) is then called **topological space**, the elements of T are called open sets of X.

The definition of topological spaces is very general and multiply usable, especially for describing rich concepts of spaces. Further specifications are very much compatible with our spatial intuitions in the context of work Euclidean spaces. Therefore, another definition may be given to obtain more appropriate spaces for distributed manufacturing considerations.

A topological space X is called **Hausdorff** if every pair of points can be separated by open sets.

That is, if $x_1 \neq x_2 \in X$ then there are disjoint open sets U_1 and U_2 with $x_1 \in U_1$ and $x_2 \in U_2$.

The idea behind the definition of the original space is to offer mappings that include properties of continuity, so the space elements and their later mappings are closely related.

If X and Y are topological spaces, a (homeo)morphism from X to Y, Ø is a map X to Y, so Ø and their interactions are continuous. This definition leads to the conservation of properties of the spaces when projecting onto other spaces.

A topological space X is said to be a **Hausdorff space** if given any pair of distinct points, there exist neighbourhoods; this property is often summarized by saying “points can be separated by open subsets”. The Hausdorff property ensures that a topological space has subsets, all to form to our spatial intuition. For many purposes, it is useful to restrict attention to spaces that do not have too rich subsets. This construction may be ideally used for attaching spaces that represent reductions of the original, as valuable for CPS.

On these open subsets topologies can be defined that are related with the topologies and are, under certain conditions, called **quotient topologies** induced by maps **f**. The theory of quotient spaces gives ways to construct new topological spaces by attaching. The quotient spaces Y are also called **adjunction spaces**, and is said to be formed by **attaching to** X along **f**. The map f is called the attaching map. This view captures the intuitive idea of attached spaces e.g. alike Euclidean spaces, spaces and we daily deal with. For virtualisation is of objects, and this view gives the sidelines for all constructs use in distributed manufacturing, as not the systems itself but models thereof are communicating, interacting and linking. As several aspects are involved that underpins the importance of different mappings originating from the same unit and still being somehow related. Negation interaction and linking can be done with any of the mappings without contradictions, as long as correspondent granularity is ensured. This gives also sidelines for standardisation needs in distributed manufacturing.

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