9 Conclusions and Outlook

This edited book has presented a selected range of contributions, based on the results of the EU Plant Automation Based on Distributed Systems (PABADIS) and PABADIS based Product Oriented Manufacturing Systems for Re-Configurable Enterprises (PABADIS'PROMISE) projects: from methodological to theoretical to address the issues surrounding Distributed Manufacturing. The contributions neither claim to have completed all the research necessary on the field nor to be the final stage of development of principles, methods and instruments resulting from network thinking in manufacturing. It must be noted that the "distributed" perspective on manufacturing, implicitly introducing the modes of iteration, parallelism, emergence, behaviour and encapsulation, reveals a surprising number of novel functions, creates new problems for methodologists, and generates demands for better information and communication technologies (ICT) pervasion. However, for now this recognition can only partly result in coherent descriptions of relevant (interdisciplinary) contributions for Distributed Manufacturing.

This volume will not conclude without an attempt to synthesise all approaches outlined and to summarise key challenges that further research needs to address in Distributed Manufacturing and the implications that this way of interpreting manufacturing and resulting research has on practice.

9.1 Contributions of the Book

What follows from the contributions is that the potential of Distributed Manufacturing is manifold. It covers a number of different areas, all enhancing flexibility, efficiency and performance.

Firstly, many approaches as well as contributions appear from different disciplines, a fact that is generally cited as being very fruitful, as it nearly guarantees novel solutions and mind opening insights. Aside from the complexity thinking there are also substantial inspirations from neurobiology, topology, computer science, social behaviour studies, and artificial intelligence. This may be interpreted as a lack of theory as a solid base for manufacturing networks in general and Distributed Manufacturing in particular. Challenges will be the resistance to overcome systems thinking while at the same time transferring all comfortable properties, such as decomposition, formalisms to describe input/output and behaviour, or the selection of aspects and attributes for the networked world.

Secondly, the involvement and the exploitation of complexity principles for manufacturing networks are inevitable and favourable at the same time. Their consideration synthesises new philosophies and progress in technology. The challenges for an organisation operating loosely connected units and actors as customer-oriented networks bring us back to the potentials of ICT and the web. Distributed computing, data warehousing and knowledge bases are contributing research fields on the data processing side; on the communication side, security issues, pervasive technologies, augmented virtual reality, blogging and shared data applications are important fields.

Thirdly, the harmonisation of models and procedures used for management and successful coordination of network behaviour can be achieved by reasonable input of resources. Practitioners that are fully exposed to the challenges of Distributed Manufacturing networks still have to rely upon accustomed instruments that are developed for one time static setups' management. The contributions confirm the evidence that next generation instruments will have to support the optimisations of 'transvariable' indicators (such as value addition, time) instead of 'intervariable' attributes (such as output, volume). Network performance is measured by the quality and the speed of linkage. The specific experiences with prototypes underpin the fact that next generation management will operate also on methods originating from Distributed Manufacturing as described.

Distributed Manufacturing is a powerful structure for coping with market volatility by sharing knowledge, resources and risks in new product developments. For the success of these activities, the concurrency of operations is a vital issue. In Chap. 1 Hidalgo thoroughly explores concurrency in product development in the much tight interfirm context of the extended enterprise (E2). At this level he sees a field of distributed product development as the aggregate pattern of product introductions emerging over time. In order to cope with volatility he calls for robust product families for the creation of numbers of derivative products, founded on a common core technology – the product platform. This idea constitutes a red thread throughout the book as design pattern in Chap.6 or as ability application environment in Chap.7. Success results from concurrent evolution of product families, platforms and product creation. Only close collaboration and intensive standardisation may provide efficient common processes as well as successful innovation. The resulting way of value creation assumes new instruments, other coordination mechanisms and interlinking ICT tools, which are outlined in principles and examples. This statement is repeated in Chap. 3 with respect to factory design.

More generalised and motivated by biological evolution, and not confined to new product development, Dekkers discusses the very "prototype" of collaboration and concurrency, co-evolution. The basic idea is to identify collaboration as a strategy for the phenotype to survive, whose success is expressed in the fitness of an agent or an entity. It is the basis for descriptions of dependencies and mutual developments, which yields additional insights on the interaction and interrelation of entities. Companies engage in new relationships in order to increase their fitness underpinning the importance of new and more effective models to support the dynamics of collaborative relationships, as proposed in Chap. 4 by different highly collaborative factory set-ups or in Chap. 5 by several "X"-reality approaches or community approaches. The theories developed there are very valuable ingredients for a synthesis to advance our understanding of concurrent enterprising and how distributed structures address collaborative challenges in industrial networks. Therefore they define the framework for the metrics and indicators to be applied to the network topology that can only logically describe network set-ups and processes representing valuable input for software design and software agent programming.

Wünsch et al. explore the technical and operational interpretations (focusing on ICT) of distribution and concurrency by synthesising various aspects of flexibility, product, technology and resource. Three prevailing information technology paradigms – object orientation (OO), service oriented architecture (SOA) and agent oriented architecture (AOA) – are mirrored in the most important manufacturing principles that have emerged in leading companies in order to better cope with the concurrency needs of multistream processes. These principles may be seen as responses to environmental problems (green manufacturing), network thinking (collaborative manufacturing, visual manufacturing, mobile manufacturing, and reconfigurable manufacturing) and decentralised parallel computing possibilities (open manufacturing, harmonised manufacturing, event-driven and real-world manufacturing). All items discussed are viewed as constituents of mechatronic systems as the preferred application area for next-generation Enterprise Resource Planning (ERP). The authors could verify that the "PABADIS world", which serves as the foundation of all contributions of this volume, perfectly enables one to exploit the three information technology paradigms and can be engaged to successfully cope with all identified challenges. It is concluded that next-generation planning and execution systems will be based on architecture like PABADIS fully integrating process and management levels. This comes up in all Chaps. 4-8 as a result of commonly used ICT standards, but especially for coherently applied methods and platforms.

It is generally anticipated that people will be working more as dynamically assembled groups of diverse and complementary skilled professionals within an enhanced collaboration environment. Therefore, a number of communication means have been successfully introduced, each offering specific profiles for support. Pallot and Bergmann take a critical look at such implementations revealing that most of the set-ups do not need teams working together in one place, although most of the solutions are applied in this way. The team members may be distributed at a number of different sites. Moreover skills and benefits as well as adoptions of such communication media prove to co-evolve with all other ICT applications, a key point in Chap. 3 as well. These findings again confirm instinctive feelings of managers strongly signaling that especially the gains of the prefabricated expensive "X"-reality set-ups could lag far behind expectations even in the long term. Companies which are enthralled by the potential of augmented reality (AR) to communicate e.g assembly instructions in real time in their factories should consider the potential damage that could arise if skills learning were not enabled. Chap. 4 endorses other recent experiences and field study outcomes that, contrary to all predominant views, the formulation and communication of information should be designed using ICT, and distributed decision support may be added using agent architecture as such multi-agent systems (MAS) set-ups outlined for manufacturing execution systems (MES) in the Chaps. 5-7. In particular, the failure to develop and harness human expertise can lead to companies becoming uncompetitive, because of expensive and powerful ICT investments as well as the role of agents to better meet the requirements is one important strand of research, outlined by Bratukhin et al.. Agents are introduced as means to decentralise decision making by detaching it from the top levels. This is a precondition for the decentralisation of control. The design patterns used to describe the control set-ups are interpreted as generically consisting of two main elements: resources and costumer orders. To cope with complexity the agents' structure is aggregated or disaggregated hierarchically, by implicit use of self-similarity principles as well as synchronisation methods to ensure concurrency options. The basic structures addressed by the majority of the most important approaches are derived from these generic set-ups. The advantages of all approaches are synthesised for advanced MES solutions in factory automation which is compatible with the resource planning levels as discussed in Chap. 3.

Sauter and Tretyl take up Distributed Manufacturing from the fieldbus level and the variety of solutions that already exist, exploring the limitations of real-time applications. A major issue is finding suitable mechanisms for synchronisation and security. The historical review leads, over important communication paradigms – client-server, producer-consumer, and publisher-subscriber models – to the potential of the Internet with its multiple ways of synchronising and providing for security. Tightly coupled as well as loosely coupled units may be connected by the World Wide Web and installation of rigid zones and flexible domains. The set-up proposed by PABADIS is strongly emphasised as adequate and most instructive for future automation systems. Moreover, bionics is recommended as the general view to be followed and softer models, as outlined in by Bergmann and Pallot in Chap. 4, have to be increasingly included if higher levels of complexity for distributed manufacturing are to be covered.

Lüder et al. thoroughly analyse the distribution issues on the lowest control level implemented by field control systems. Here the focus is on knowledge preservation related to the most efficient and often used structuring paradigms valid for distributed field control applications. Therefore, the design pattern as an appropriate means to code solution knowledge within different areas of science and practice is explored. Design patterns were initially developed in architectural sciences for describing generic solutions in the problem area as well as the solution context. They quickly have been transposed to information science and a number of other disciplines and serves as a perfect base of integration for all preceding contributions. With this last chapter the most appropriate design pattern for the segmentation of field control applications to distributable entities, for enforcement of the reusability of field control application segments, and for positioning of these segments on control devices is outlined. An application case making use of these design patterns is explained highlighting the greatest benefits of the approach.

9.1.1 What are the philosophies to manage Distributed Manufacturing? Which paradigms and metaphors should be emphasised and encouraged for support?

The concept of the monolithic manufacturing company is definitely obsolete. The "certainties" and the full "hierarchic controllability" of companies have always been comfortable pretences or even most welcome excuses for inflexibilities or insistence on organisational standards. Under pressure and in dynamic environments such illusions vanish, and – upheld through inertia – will even develop into a fatal threat for companies. As successors several new concepts have arised. These concepts are not just static and systematic; they draw from such dynamic backgrounds as the theory of constraints (lean manufacturing), biology (bionic manufacturing), nature (holonic manufacturing) and geometry (fractal organisation). None of these concepts may fully cover the Distributed Manufacturing field. Complexity modes (encapsulation, iteration, behaviour) as well as concurrency structures (parallelism, emergence) had to be emphasised to furnish adequate grounds for engineering and management of Distributed Manufacturing. Collaboration frameworks (e.g. company footprints), facilitating self-organisation and guidance of self-interested interrelated actors, accelerate implementations and instant stabilisations of reliable structures and help to define adequate measuring and monitoring indicators.

9.1.2 Which disciplines and models are likely to further develop the methods and instruments for Distributed Manufacturing structures? How about the trends in information technology and their effects on coordination and management of inter-organisational value chains?

Among the contributing disciplines we find complex adaptive Systems theory, decision theories, sociology, theory of multi-agents, evolutionary biology, zoology, organisation theory, topology, artificial intelligence, and network management. Within all these disciplines there have been successful attempts to investigate and describe the phenomena of collaboration and networks and the changes that are taking place in relation to industrial organisations. However, to date there has not been published an edited comprehensive account of the different perspectives that exist among the various academic and industrial research communities striving for an emerging new network science.

Ambient intelligence and mobile connection of (distributed) expertise, knowledge and creativity will be the important next ICT features. Open data sharing networks and social webs could link people, units and organisations. Business legal entities will be complemented by social legal entities. Cutting-edge knowledge and high-skilled individuals will be increasingly organised outside of manufacturing companies e.g. in professional virtual communities (PVCs) or comparable organisations. Products and value-adding services will increasingly rely on embedded intelligent devices, affecting the users' individual security and privacy. As increasing numbers of people will neither be able to understand the mechanisms of the (also networked) products nor classify the risks of the products and processes, deeper involvement of people in development and innovation, e.g. by offering open source or living laboratories, might become an important company activity. Anticipating problem areas, synthesised with company-specific sustainability priorities, might strongly direct companies' public relations activities. Accounting may have to provide transparency in all areas pointing out successful contributions to higher societal goals as well in order to maintain the highest acceptance of its behaviour. Surely, a manufacturing world of collaborative ICT is emerging. Human resource policies should put a premium on collaboration skills, ICT capabilities and readiness for IP connection anywhere and anytime, as these will be the decisive factors.

9.1.3 How can companies self-position in times of vanishing distinction of organisations from their environment? Do organisation theory and management science need to be extended by a number of new chapters covering decentralised and distributed processes and value chains?

The scope of collaboration among enterprises has widened substantially. In Distributed Manufacturing the creation of value will take place simultaneously and at various locations. Knowledge about the capabilities of potential partners is becoming a part of the know-how of an enterprise. A company thus needs to continuously determine its position in the market as well as within the network. One key attribute is the core capability, as the Distributed Manufacturing approach relies on the implications of variation, selection and retention. In the manufacturing networks arena, there are specific capabilities in a network of manufacturing plants above and beyond those at the factory plant level. The extension of capabilities to beyond the firm calls for a process-based analysis of capability development, as well as an outcome-based assessment at the strategic level. A central issue is the development of metacapabilities, involving "selective resource picking"; the selection process seeks to achieve a particular outcome or alignment to the business model and thereby provides for a unique "metalevel capability" that is not yet understood. These metacapabilities seem to be company (or network) specific, customer relevant and business aligned.
Apart from the basic trust generally expected by business ethos, the level of trust in networks is closely linked to the partners' behaviour. Real trust builds e.g. under extraordinary circumstances in which one partner is willing to meet exceptional requests, above and beyond the agreed terms of business. The mechanisms for establishing and keeping high levels of trust, absolutely crucial for manufacturing networks, still are very little understood. Trust is the foundation of collaboration on the MES level as well, where most of the security problems in the ICT fields remain unsolved. Technical as well as organisational solutions are far advanced however, important lessons have not yet accessed the inner body of knowledge in manufacturing and management. Interesting possible advances, such as e.g. web-based manufacturing operating globally distributed technical units via Internet communication, have therefore not been made. ICT education and training on software and devices has not reached maturity levels permitting to enable entire staffs of manufacturing networks skilled and efficient use at reasonable cost. Most productive technologies and solutions remain restricted to ICT expert use so the broad effects lag far behind expectations.

Whereas concurrency thinking is well established in engineering, its extension to enterprise networks is a very recent phenomenon. This fruitful extension takes place gradually as many benefits and achievements in distributed manufacturing structures fertilising quasi-unconscious and unarticulated approaches in numerous fields originate in concurrency set-ups. All chapters in this book indicate that the work is not yet finished. In fact, all authors point to avenues of future work.

9.2 Implications for Practice

What follows for industrial practice is that non-hierarchical views of manufacturing will become fully established. In the first place, the concepts of planning and control will replace central, sequential, rhythmic and time-sliced procedures by event-driven parallel distributed evolving logics. Manufacturing will introduce and apply new types of methods and tools, supporting linkage and reconfiguration as well as acquisition of high-level plug and produce, plug and participate and concurrent work skills. Atomisation of production equipment and flows into intelligent units will enable every unit to manage and control its flow process autonomously. Humans and units as well as units and units will communicate or even negotiate.

Concerning ICT in industry, maximum attention has to be paid to all developments of networkable devices, as they will increasingly influence organisational structures as well as decision-making procedures. This will be the most important challenge for interoperability and data security resulting in the complete revision of enterprise resource planning system architecture and man-machine interfaces. New worker types may emerge making use of all ICT options and collaborative working environments relying on permanent Internet connectivity and social touch via web applications. An expected shift from individual productivity towards interpersonal productivity could engender novel intellectual property rights (IPR) situations and might force manufacturing companies into stronger involvement in communities of practice and on-line communities. A shift of power towards Professional Virtual Community structures is a possible consequence, so companies are likely to experience that individuals' working contracts will be managed by these organisations and communities, models far beyond any actual management scope.

In addition, the practical work with the prototypes has once more proven the high potential of new ways of collaboration in distributed manufacturing. Mastering complexity will be one of the major topics for future manufacturing. A specific production network management science for developing and incorporating new networking instruments may appear. As the new ways of looking at manufacturing are not yet fully settled in widespread methods and tools, the challenges compel managers to contribute further insight and collaborate with academics to advance both practice and theory.

Reponses to new order volumes will be rather relinking or renegotiating links with network partners and contributing to the common trust base with the highest reliability. Dedicated training activities aimed at promoting teamwork on a worldwide basis are necessary for the emergent concurrent way of working.

On the way to concurrent enterprising (CE), following up beyond Distributed Manufacturing, more research needs to be put on the agenda. As the papers invited for this book indicate, the unanswered questions can be examined through a wide variety of approaches, both theoretically and methodologically. We hope that the papers and themes outlined will spur more research to further examine this fascinating area.