From Industry 4.0 to Research 4.0. Development of high-performance fibres in the light of digitisation

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Abstract

The research work in the field of high-performance fibres is characterised by a high degree of adaptation needs. Research facilities must be able to be adapted after initial experiments and the knowledge gained thereby. The necessary adjustments are made under the conditions of a highly complex manufacturing process, which is determined by many influencing parameters. The development of high-performance fibres demands an efficient system and, in part, self-optimising experimental working system, which must be intelligent in gathering data from the process and flexible in enabling the rearrangement of the process. Research 4.0 is a systematic approach aiming to support researchers working on the development of innovative yarns. Each module within the line represents a production step and is equipped with a PLC to control itself and to organise in association with other modules in the plant. The control hierarchy has an intelligent modular structure that configures itself according to the arrangement of every single module given by the hardware and the interfaces within the system. This paper will present the implementation of Research 4.0 as a tool for the development of a product from the idea to the practical implementation. Such a task needs a modular conceptual approach offering the required flexibility for the complete validation process: principle > process > product.

Keywords

Industry 4.0, Research 4.0, High-Performance Fibres, Development, Modular Design, Pilot Plant, Lab-scale Plant

Citation

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1.0 History of Digitisation

In the old, analogue world, there were things above all. Things were linked to names and pictures. Thus, the world of words and the world of images developed into the first stages of abstraction. The next level of abstraction was the mapping of things, words and pictures into numbers. That was the birth spark of the world of data.

The most common way to define the world of numbers is by using ten digits (0 to 9). However, it was the invention of the binary number system by Gottfried Wilhelm Leibniz (1697) which allowed the representation of all numbers with only two digits (0 and 1). Thus, the world became mathematical and the fundament for digitisation was laid as it is the process of putting information into the form of a series of numbers 0 and 1 so that it can be understood and used by a computer or processed electronically. In 1788, Joseph-Louis de Lagrange represented in this work "Méchaniqueanalitique" the thesis, that the world can only be completely described using algebraic operations, hence turning the mathematical description of the universe into a digital realm.

George Boole proves in his work "An Investigation of the Laws of Thought" (1854), that logic and algebra are identical. Gottlob Frege followed with his "conceptual notation" of non-symbolic terms in "The Foundations of Arithmetic" (1884). This analysis of logical concepts and the machinery of formalisation was essential to Bertrand Russell's and Alfred North Whitehead's"Principia Mathematica"(3 vols., 1910–13), to Bertrand Russell's theory of descriptions, to Kurt Gödel's (1906–78) incompleteness theorems, and Alfred Tarski's (1901–83) theory of truth. These theories paved the way for mapping thinking to logic and logic to math. Thus, the base of programming languages was created and algorithmic languages like ALGOL 60 were the first breakthrough in digitisation.

In parallel to the mathematisation of the world, a multitude of

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inventions were still necessary to link things, words and images as well as sounds too logical data. The development of telecommunications from Heinrich Hertz (1886-1888) to the transistors of John Bardeen, Walter Brattain and William Shockley (1946) gave birth to wireless radio technology, which has enabled the transmission of data through the space separating emitter from the receptor. On this basis, the technical infrastructure of a digitalised world emerged. The developments such as telegraph, telephone, television, radar, broadcasting, satellite and finally the Internet have been shaping the technical network that today enables global data exchange.

In the twentieth century, based on technical innovations combined with computer technology, a closely linked communication and information network of mobile media emerged, which forms the basis for today's visions of the future. With the convergence of the various communication technologies on which the various digital control systems are based, the basis for the Internet of Things has been laid and thus for Industry 4.0 and Research 4.0.

2.0 Industry 4.0

In 2012, the German Federal Government set up a group of experts to analyse the opportunities and perspectives of information and communication technologies. As a future project of the high-tech strategy of the Federal Government, Industry 4.0 was born as a working concept. A group of experts was assigned the task of investigating the possibilities of information technology and digitisation in production research. The topic should be analysed across industries and disciplines for Germany as a business location. The inclusion of disciplines outside of the industry creates accents and emphases far beyond the core topic.

The core element of the "Industry 4.0" concept is the intelligent factory - the smart factory. The expert group appointed by the German Federal Government defines the concept of the intelligent factory as follows: "It is characterised by a new intensity of socio-technical interaction of all actors and resources involved in the production. The focus is on the networking of autonomous, self-controlling, self-configuring, knowledge-based, sensor-supported and spatially distributed production resources (production machines, robots, conveyor and storage systems, operating resources), including their planning and control systems. The smart factory is characterised by end-to-end engineering that includes both production and the product that seamlessly meshes the digital and physical worlds. The smart factory is also embedded in cross-company value networks. "

From the perspective of information technology, the eye-catching name "Industry 4.0" is used to: “propagate the widespread entry of information and communication technology and its networking into an Internet of Things, Services and Data that enable real-time production capability. Autonomous objects, mobile communication and real-time sensors allow new paradigms of decentralised control and ad-hoc design of processes. The ability to respond quickly and flexibly to customer requirements and to economically produce large numbers of variants at low batch sizes will increase and thus increase competitiveness once again. New forms of customer-integrated business processes become possible. The full-bodied promised "fourth industrial revolution" seems within reach.”

Therefore, the technology should be intelligent and able of organising itself. The production line is divided into modules, which become cyber-physical systems that network with each other. Ahrens tries to get to the bottom of this terminology and delimited the artificial intelligence of technology from the human-centred concept of intelligence. He puts it: “Against such a background, it does not matter if technology is artificially intelligent or not, but on the fact that it supports people in bringing their intelligence and autonomy to full effect.”

3. Transferring the principles of Industry 4.0 to Research 4.0

Adapting a definition of the main four goals in Industry 4.0 made by the German Federal Ministry of Education and Research , a future project Research 4.0 shall aim to enable the development of innovative products (e.g. high performance fibres) by achieving the following goals:

- Delivering a high degree of flexibility in the spinning plants under the conditions of high adaptability of the processes to new findings from the research work.
- Equipment suppliers and researchers work in close cooperation during the decision-making and development process.
- The development of new products is accompanied by high-quality services.
- Intelligent monitoring and decision-making processes are designed to enable researchers to control their experiments in real-time and to easily make optimisation adjustments.

VDMA (the German Association of the Mechanical Engineering Industry) has developed a toolbox to support idea generation in the context of Industry 4.0. The stages of development represent the path to the realisation of the visionary final stage of Industry 4.0. We have tried to measure and evaluate our development according to this realisation concept.

The toolbox allows the comparison of products with a benchmark of different goals that need to be met for a successful implementation of the vision of Industry 4.0 :

- ◆ Product related aspects
    - Integration of sensors/actuators
    - Communication and connectivity
    - Functionalities for data storage and information exchange
    - Monitoring
    - Product-related IT services
    - Business models around the product

- Production related aspects
  - Data processing in production
  - Machine-to-machine communication M2M
  - Company-wide networking of production
  - ICT infrastructure in production
  - Man-machine interfaces
  - The efficiency with small batches

4. Implementation of Research 4.0 – MultiMode®

Research 4.0 at DIENES aims to enable researchers to work on their development optimally supported by the system. The approach chosen has been a human-centred approach to create a system that can operate autonomously and with the capacity to organising itself. Either the starting point is a technology that shall be equipped with social skills and characteristics such as intelligence, autonomy and self-organisation, or the human being is the starting point and the technology is the one to be reshaped to better support people in bringing their capabilities and qualities to full effect .

The research work in the field of fibre development is characterised by a high degree of adaptation needs. The research facilities must be able to be adapted after initial experiments and the knowledge gained thereby. The necessary adjustments are made under the conditions of a highly complex manufacturing process, which is determined by many influencing parameters. This results in the following requirements for the flexibility of the electronics control of the research facilities:

- INTEGRATION: Easy integration of new production modules
- SCALABILITY: Easy replacement of production modules with modified specifications (e.g. throughput).
- FLEXIBILITY: Easy change of the order of production steps through configuration and integration of measurement and analysis sensors through multi-loop control
- HIGH PERFORMANCE: Intelligent production modules for fast process interventions and synchronisation of the process control by a master control
- ANALYTICS: Convenient monitoring and evaluation options of the process parameters by a higher-level configurable PC-based process monitoring system.

The development of new innovative filaments demands an efficient systematic and, in part, self-optimising experimental working system, which must be intelligent in gathering data from the process and flexible in enabling the rearrangement of the process. DIENES' implementation of the Research 4.0 approach is called Multimode®. Due to its flexibility, Multimode® offers a tool for the development of a product from the idea to the practical implementation. Due to its modular conceptual approach, a MultiMode® pilot plant is suitable for the complete validation process:
principle ➔ process ➔ product.

	1st Phase Validation of Principle	2nd Phase Validation of Process	3rd Phase Validation of Product
Filaments:	1 – 50	20 - 400	100 – 4.000
Threadlines:	1	1	1-4
Melt spinning:	100 – 500 m/min	300 – 1.500 m/min	1.000 – 5.000 m/min
Wet spinning:	5 – 25 m/min	10 – 100 m/min	20 – 200 m/min
Throughput:	10 – 250 g/batch	100 – 1.000 g/h	1.000 – 10.000 g/h
		x10	x10
Machine size:	300 x 100 mm	3.000 x 500 mm	30.000 x 1.500 mm

Figure 1 - MultiMode® – Validation process of principle, process and product (Source: DIENES)

5. The structure of the MultiMode® system

Under Multimode® every module represents a production step and can store knowledge at the module level and act according to the function of the module in interaction with other modules. The Multimode® system runs on three levels:

- Slave (level 1 - MMS: MultiMode® Slave)
- Master (level 2 - MMM: MultiMode® Master)
- Upper control (level 3 - MME: MultiMode® Explorer)

The requirements for a flexible control system have reached a very high technical level alongside expectations from the user regarding ergonomic demands for the interaction with HMI (Human Machine Interface) and the equipment. The MultiMode® concept fulfils the following requirements:

- Easy extension or reorganisation of the modules in the system.
- Various process ideas can be tried out in one day by modifying the modules.
- Enables the operation of individual modules outside the plant.

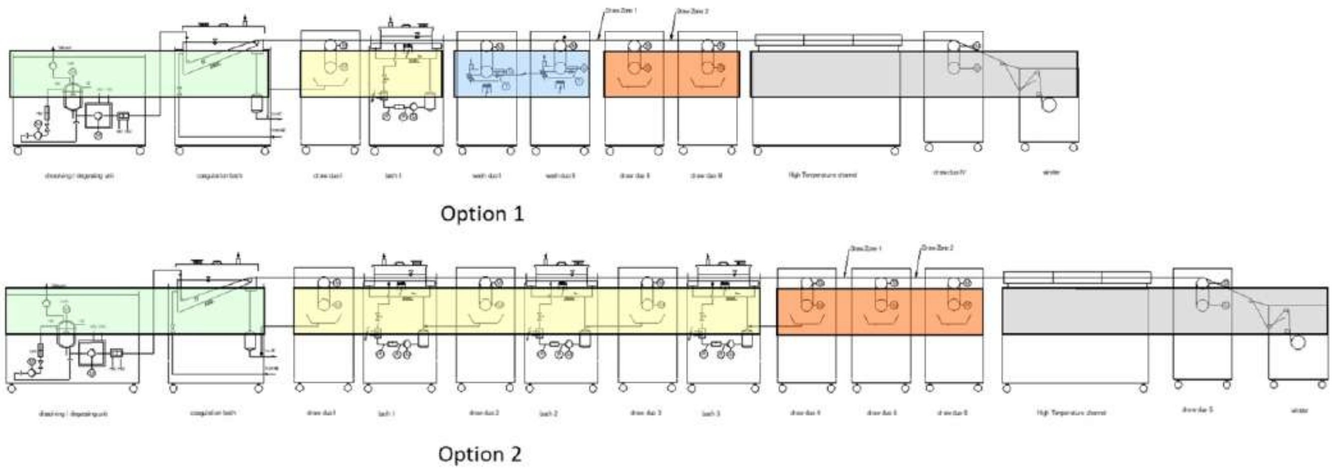

Figure 2 - MultiMode® – Configuration change without programming (Source: DIENES

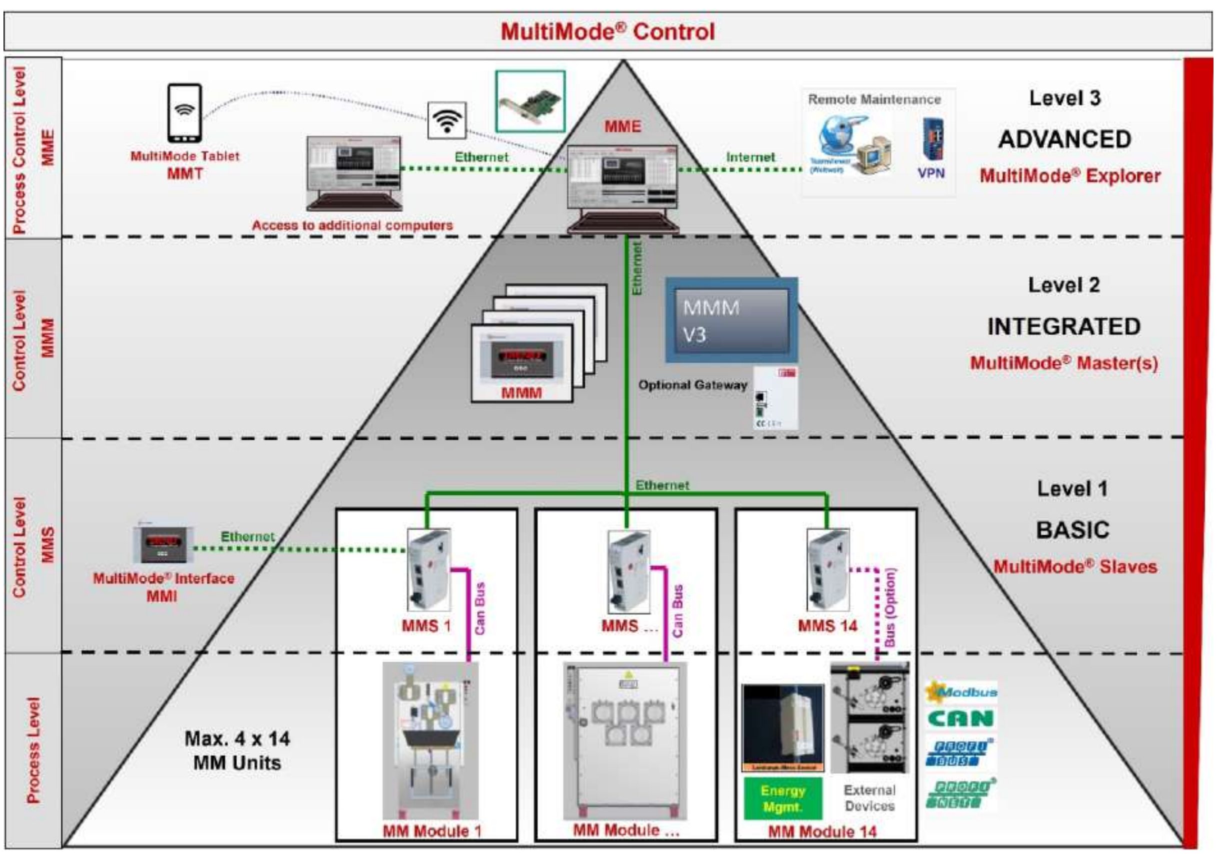

Figure 3 - MultiMode® – Hierarchical structure (Source: DIENES)

The configuration of the system follows a hierarchical structure. The foundation is formed by the yarn treatment modules such as the washing duo, washing bath or spinning unit. Each of these MMS modules is equipped with a MultiMode® box, hence it is equipped with its intelligence based on a PLC to control itself and to organise the module in association with other modules in the plant. A single module can automatically take over a thread from a non-MultiMode® plant and process it, e.g. as an additional drafting stage or to eject a thread from a system and wind it up.

Control hierarchy has an intelligent modular structure that configures itself according to the arrangement of modules given by the hardware and the interfaces within the system. Thus, a structure is realised that allows new arrangements by configuration and without any programming work required. From a control perspective, the process level with the MultiMode® boxes forms the control level "BASIC" with the MMS modules. Up to 14 of these basic modules can be switched to one MMM. This second control level "INTEGRATED" is organised by the MMM, which is also responsible for configuring and forwarding the information to the computer-based MME. The computer level control (MME) can be connected with 4 MMMs, which gives the possibility of 56 MMS modules connected to their corresponding MMM with their local input displays or to an industrial PC via gateways allowing all visualisation and control options using a touch screen. The upper control level is the process control level "ADVANCED" and organises the elegant functions of the system.

The functions included at the MME include features like:

- Real-time evaluation of all sensors, which can be combined with each other in the graph
- Data logging with a connection to an SQL database every second.
- Data management. The system has the possibility to transfer recorded data to EXCEL for further analyse.
- Access control with user administration (password protected) with different access levels to the operation system
- Tracking of all operator inputs (operator login required)
- Recipe management for saving current settings as a recipe under a freely assignable name to be used at a later moment if necessary
- Alarm logging
- Mini-monitoring. Single parameters can be monitored in a small screen-in-screen application in real-time. It is possible to add additional parameters to the "mini-monitor" and generate ad-hoc visualisations making it a quick and easy way for the user to analyse correlations between different production parameters.
- Long-term monitoring of operation parameters.
- The printer function with no limitations and allows printouts and screenshots of any view or diagram on the screen.
- Notepad function for making notes on the screen. When printing the full screen, these notepads are also printed.

If the MultiMode® line is connected to a wireless network of the Internet (e.g. via VPN), the MME offers additional functions: remote access to the plant for service and operation, operating the line via mobile phone or tablet (via DIENES app), etc.

6. Evaluation of the MultiMode® system with the Industry 4.0 benchmark

In section 3 a benchmark developed by VDMA was presented as a possible way to validate the adequacy of a concept or product to the principles of Industry 4.0 . In this section, VDMA's guideline will be used to evaluate the MultiMode® approach as a Research 4.0 solution.

6.1. Product related aspects

6.1.1. Integration of sensors/actuators.

Integration of sensors and actuators has been a standard in research facilities for a long time. As an example of further integration of sensors/actuators, the speed control of godets is nowadays solved by thread tension control instead of fixed draw ratios. Thus, yarn tension sensors are used, which are analysed and interpreted to readjust the godets' drives accordingly.

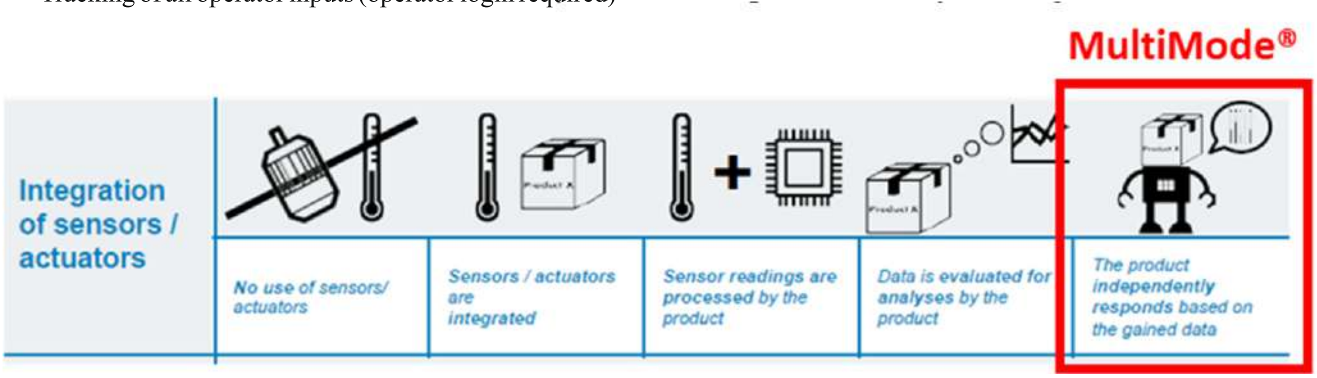

Figure 4 - Integration of sensors/actuators (Source: VDMA)

6.1.2. Communication and connectivity

MultiMode® systems have open interfaces and are able to integrate various third-party products. It is compatible with today's common BUS systems. Access to the Internet allows a remote connection with the system. Remote service and support can be delivered this way.

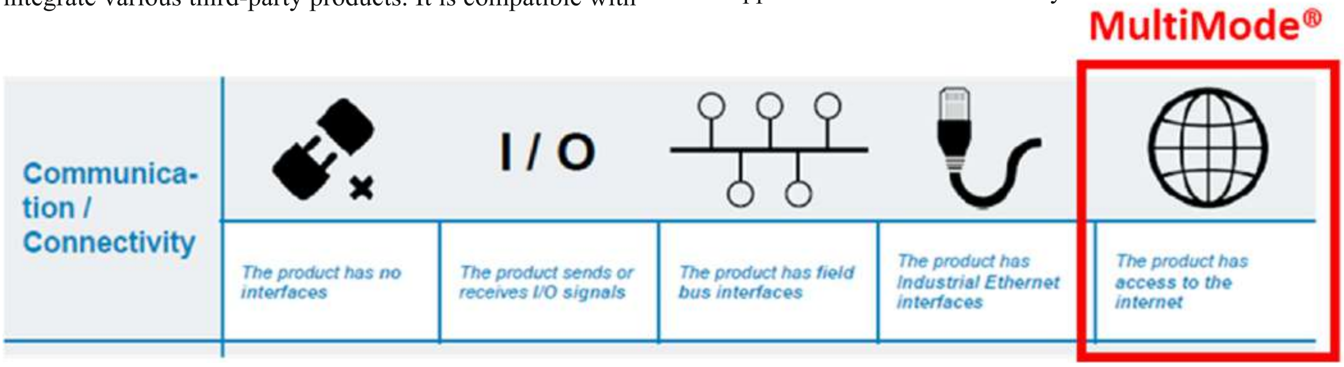

Figure 5 - Communication and connectivity (Source: VDMA)

6.1.3. Functionalities for data storage and information exchange.

The Multimode® System has an upper control system (MME) in which elegance functions are performed. This ranges from a single data monitoring that allows the researcher to explore system contexts and to analyse time series of data taken every second. To confirm correlations of a pair of data, the researcher can initiate long-term monitoring for confirmation and record the data every second within a defined time. Data can be graphically displayed. The selection of data to be recorded is arbitrary and freely selectable as every data is accessible. The system can transfer the data in a processable format (e.g. EXCEL file) for further analysis.

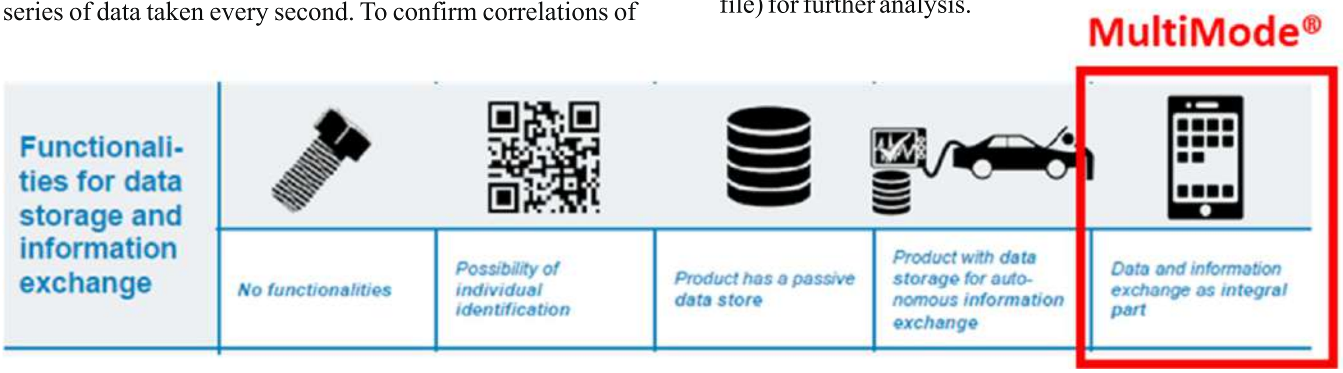

Figure 6 - Functionalities for data storage and information exchange (Source: VDMA)

6.1.4. ICT infrastructure in production

The infrastructure of Information and Communications Technology (ICT infrastructure) has different priorities in research than in production. The network does not have to go beyond the normal connection to the intranet and the normal connection within the company. Connecting a MultiMode® system to research partners is possible. Partners can access the system remotely via software (TeamViewer) and also call technical support via remote access service. Experimental design and statistical trial optimisation are still outside the MultiMode® system. Integrating these tasks and developing concepts for automation here are further development stages for the future.

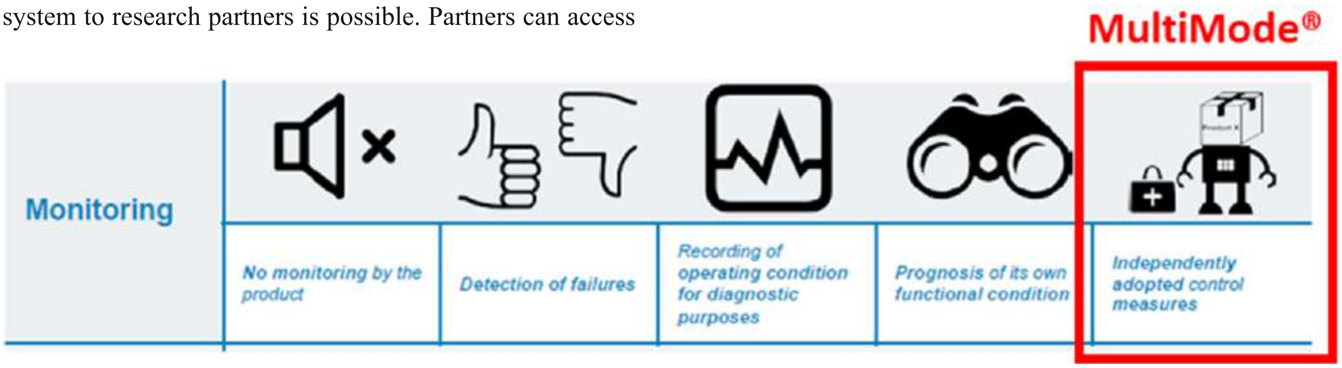

Figure 7 - Monitoring (Source: VDMA)

6.1.5. Product-related IT services

If access via VPN is granted, a full range of remote support and service is possible. Access to the line via mobile devices can be also organised this way.

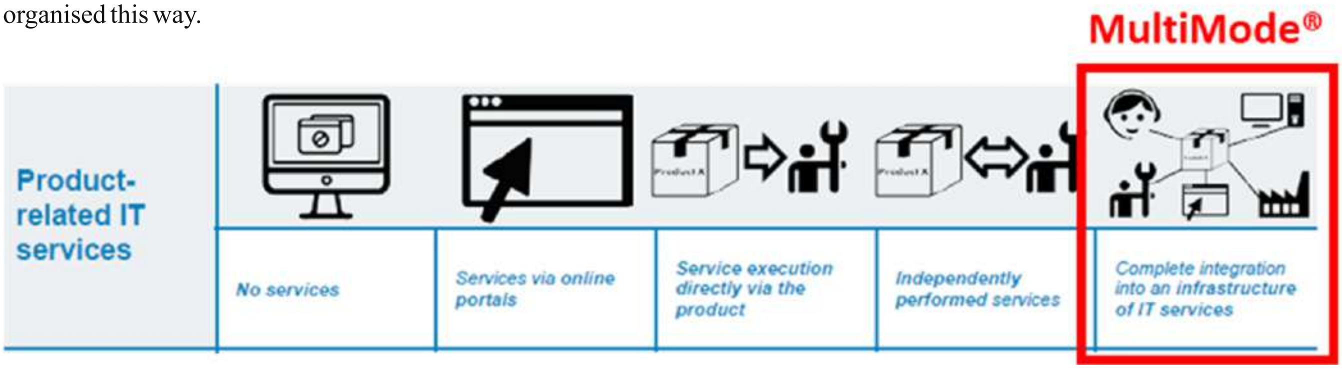

Figure 8 - Product-related IT services (Source: VDMA)

6.1.6. Business models around the product

The remote connection and the possibility to store and monitor big amounts of production data make a complete integration of services possible.

Figure 9 - Business models around the product (Source: VDMA)

6.2. Production related aspects

6.2.1. Data processing in production

Data are collected and the process is monitored automatically while the evaluation of the running conditions of the plant is still done manually. The evaluation of the dependency on various parameters is supported by analysis tools and allows systematic correlations to be identified in prototype plants in order to automate processes in subsequent production on large-scale plants.

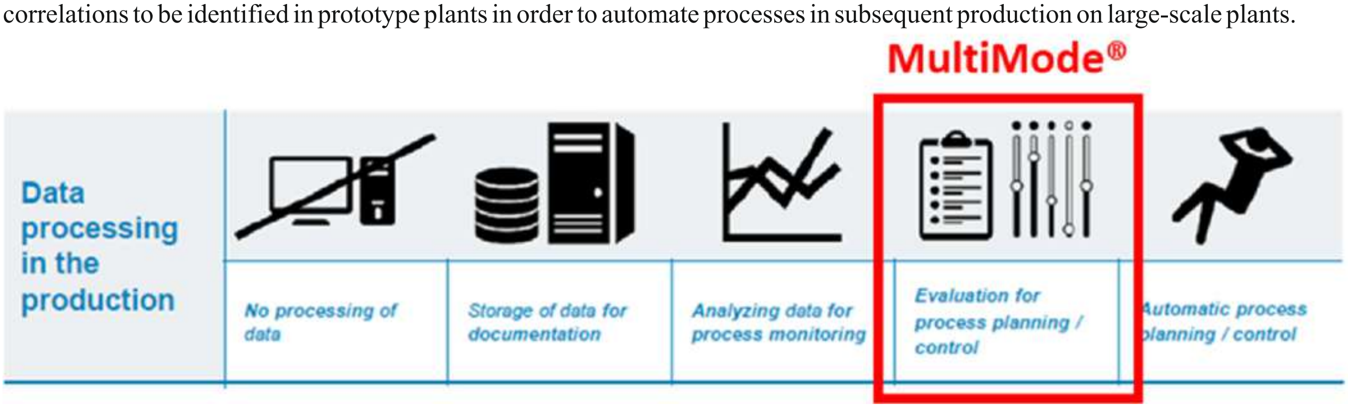

Figure 10 - Data processing in production (Source: VDMA)

6.2.2. Machine-to-machine communication M2M

MultiMode® provides the necessary interfaces for intelligent communication between the modules. A special feature is the self-organisation of the MMM after a rearrangement of the MMS modules at the machine level. Communication with external units, i.e. access to the system from the outside via mobile devices or the Internet or even reporting an alarm of the system to external devices is possible.

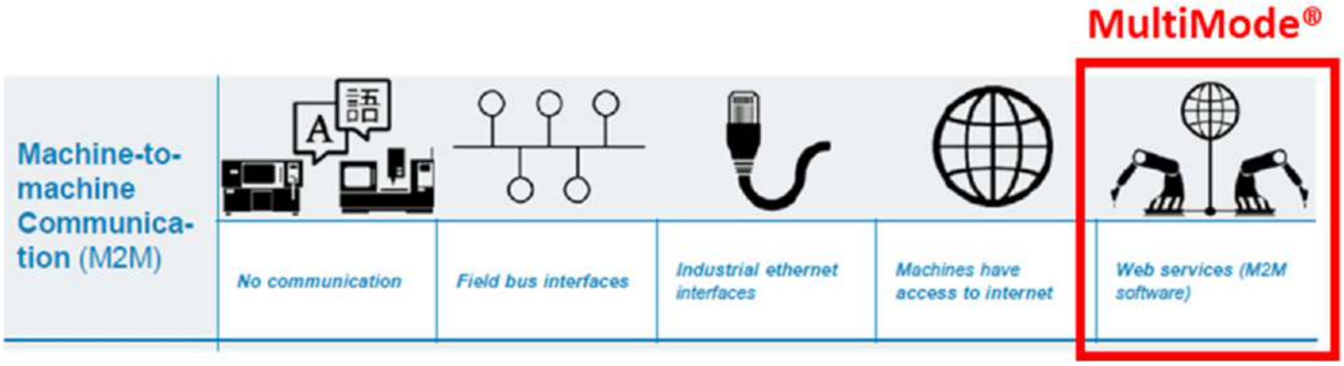

Figure 11 - Machine-to-machine communication M2M (Source: VDMA)

6.2.3. Company-wide networking of production

Company-wide networking of production

An enterprise-wide communication of the individual research results, which are obtained by pilot lines in the research departments, does not seem as a main goal. Within the research plant environment, it is possible to allocate the respective running conditions to the second of the produced yarn quantity and to communicate them within the researchers' network. This information is available in a processed format. If the research team wants it, the results from their work can be stored in a data server (SQL)which can be used as a knowledge database.

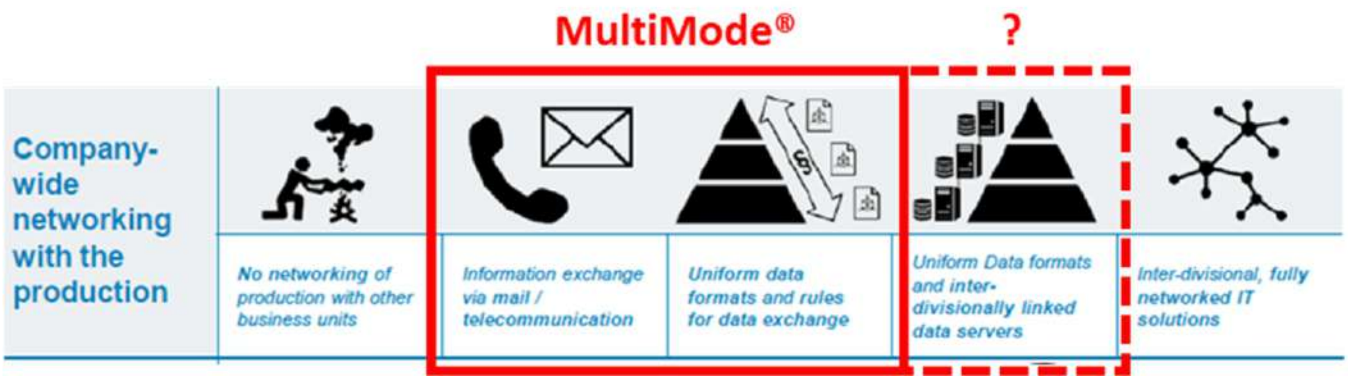

Figure 12 - Company-wide networking of production (Source: VDMA)

6.2.4. ICT infrastructure in production

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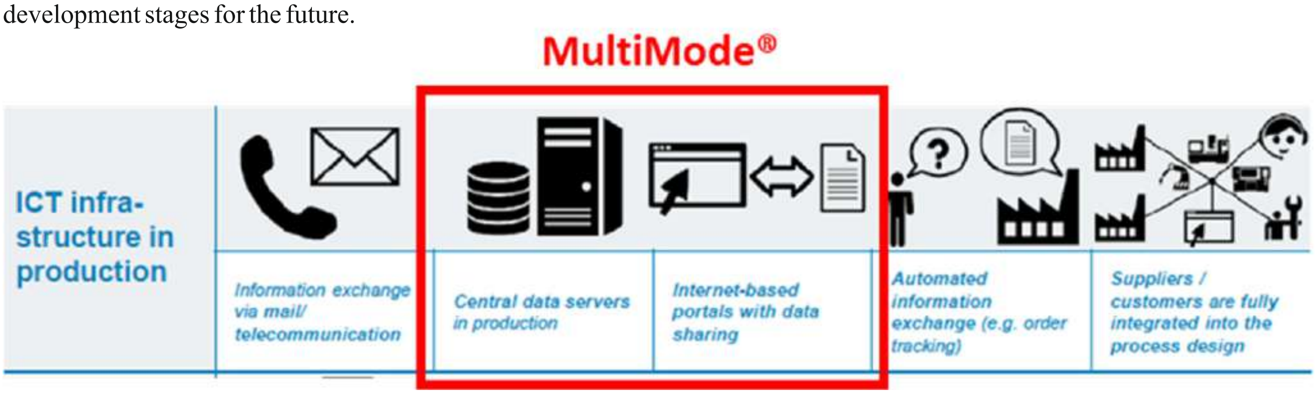

Figure 13 - ICT infrastructure in production (Source: VDMA)

6.2.5. Man-machine interfaces

The use of mobile devices allows watching and controlling functions. Apps have been currently developed that use a mobile device to exchange data with the MultiMode®control system via a WLAN limited to the system. The setting of on-site parameters exactly at the point where the yarn forms or the yarn runs over a pair of godets allows the researcher to observe the change in the process in real time. Operators don't have to walk all the way down to MMM or MME.wants it, the results from their work can be stored in a data server (SQL)which can be used as a knowledge database.

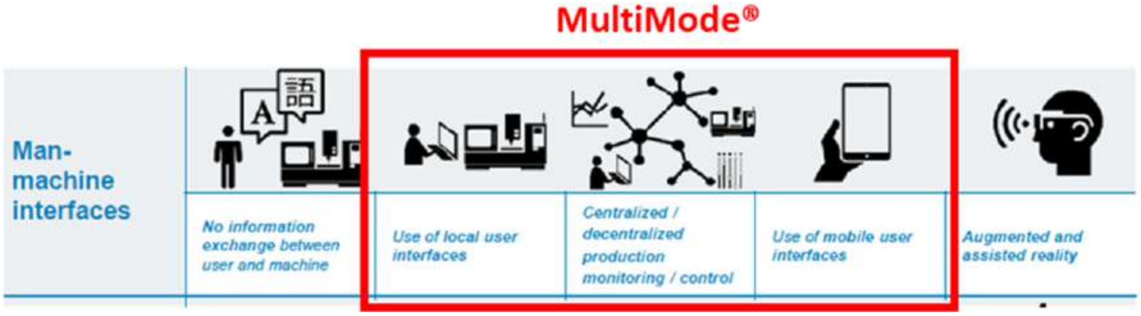

Figure 14 - Man-machine interfaces (Source: VDMA)

6.2.5. Data processing in production

In terms of a high degree of flexibility, which makes it possible to carry out experiments efficiently and goal-oriented, two tools have to be mentioned: very detailed recipe management allows the storage and use of operational parameters from already performed experiments and the continuous tracking and monitoring of operational parameters.

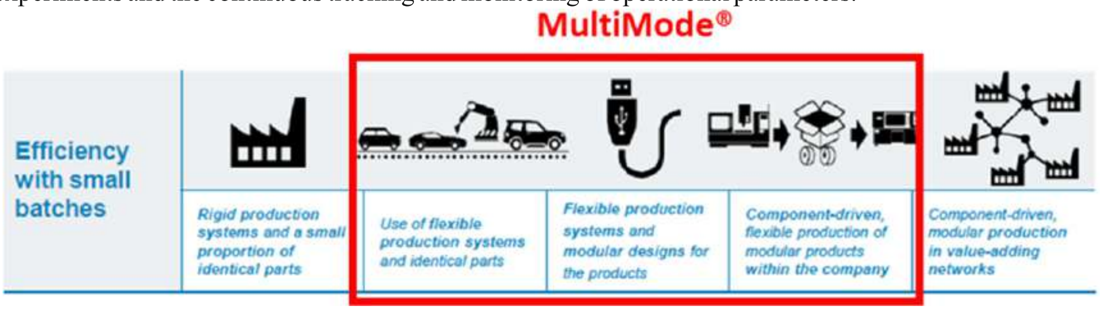

Figure 15 - Data processing in production (Source: VDMA)

7. Conclusion

Many aspects of the Industry 4.0 approach, which have been developed for industrial production, are transferable to research production facilities resulting in a Research 4.0 approach. Full integration into the logistics chain of production is less important in this case. However, the researcher needs to be enabled to manage digitally the entire process flow of his research work. Research 4.0 offers transparency within the working process and traceability of the results supporting the research team ins its creative work and keeping open all paths to innovative developments.

MultiMode® has been presented as a Research 4.0 solution developed by DIENES. The approach chosen has been a human-centred approach to create a system that can operate autonomously and with the capacity to organising itself. A benchmark developed by German experts has been used to evaluate how MultiMode®meets most of the requirements drawn for Industry 4.0. All product-related aspects are met to their full extent while some production-related need some improvement: e.g. integration of big data analysis to recognise patterns and apply them to automatic process planning and control, implementation of augmented reality solutions to enhance the man-to-machine interaction (e.g. VR googles), etc.

References

[1]Weibel, P; Infosphäre: Die Verwandlung der Dinge in Daten; 2015 ZKM | Zentrum für Kunst und Medientechnologie Karlsruhe, 2015

[2]Kagermann,H et al.; Umsetzungsempfehlungen für das Zukunftsprojekt Industrie 4.0 - Deutschlands Zukunft als Produktionsstandort sichern; Promotorengruppe KOMMUNIKA-TION; Prof. Dr. Henning Kagermann, acatech (Sprecher der Promotorengruppe) Prof. Dr. Wolfgang Wahlster, DFKI Dr. Johannes Helbig, Deutsche Post DHL; Abschlussbericht des Arbeitskreises Industrie 4.0, Vorabversion; 2012

[3]Spath, D et al.; FRAUNHOFER- Institut für Arbeitswirtschaft und Organisation IAO Studie: Produktionsarbeit der Zukunft – Industrie 4.0, 2013

[4]Ahrens, Volker; Industrie 4.0: Ein humanzentrierter Ansatz als Gegenentwurf zu technik-zentrierten Konzepten - ARBEITSPAPIERE DER NORDAKADEMIE; November 2014

[5]BMBF; Innovationen für Deutschland, Industrie 4.0 Innovationen für die Produktion von morgen; Bundesministerium für Bildung und Forschung (BMBF) Projektträger Karlsruhe (PTKA); DIE NEUE HIGHTECH STRATEGIE; August 2017

[6]Stahl, B; et al; Guideline Industrie 4.0 Guiding principles for the implementation of Industrie 4.0 in small and medium-sized businesses; VDMA Forum Industrie 4.0; VDMA Verlag ISBN 978-3-8163-0687-1; 2016

[7]Ahrens, V; Industrie 4.0: Chancen und Risiken; NORDAKADEMIE; 2014