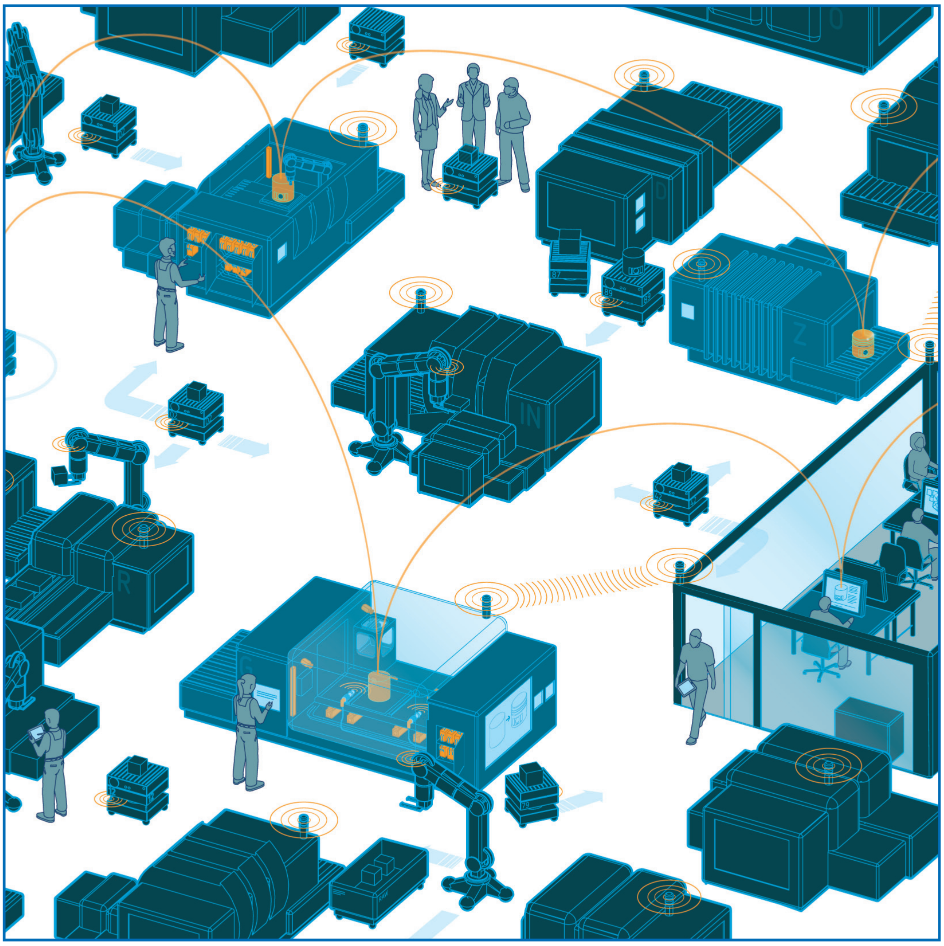
Position Paper

Industrie 4.0: MES – Prerequisite for Digital Operation and Production Management

Tasks and Future Requirements



German Electrical and Electronic Manufacturers' Association

Die Elektroindustrie

Industrie 4.0: MES – Prerequisite for Digital Operation and Production Management

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Contents

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1 Motivation and Goal

Everybody is talking about Industrie 4.0, and yet, at the start of this position paper, it appears necessary to lay out the key aspects regarding the position and role of Manufacturing Execution Systems (MES) in an Industrie 4.0 context.

The German standardisation roadmap for "Industrie 4.0" describes the underlying goal of Industrie 4.0 as being "to render the advances already made in information and communication technologies, and those expected in the foreseeable future, utilizable for production companies" [1].

From a business perspective, this is a "new stage in the organization and control of the entire value stream along the lifecycle of a product" [1]. A technical requirement for reaching this stage is specified as the "availability of all relevant information in real-time through the networking of all instances involved in value creation" as well as the "ability to derive the best possible value stream from data at all times" [1]. A key factor here is the "connection of people, objects and systems" to form "cross-organizational value networks" [1].

Unfortunately, Industrie 4.0 is often reduced to the vividly descriptive example of the "digital factory", and the self-organisation of production and communication between the workpiece and machine are highlighted as the supposed core of Industrie 4.0.

In this connection, a frequent question is then what the role of MES is in this oft-cited self-organisation. Does this make MES superfluous? Or is MES in fact a key element for attaining this new stage in the organization and control of the value stream? And, if so, how does MES need to change in order to fulfil this role? The ZVEI MES working group has addressed these questions and will now present in this paper the positions established as well as questions that arose.

2 Industrie 4.0

2.1 The fourth industrial revolution

According to Klaus Schwabe, founder of the World Economic Forum in Davos, "we stand at the brink of a technical revolution that will fundamentally alter the way we live, work, and relate to one another. In its scale, scope, and complexity, the transformation will be unlike anything humankind has experienced before. We do not yet know just how it will unfold, but one thing is clear: the response to it must be integrated and comprehensive, involving all stakeholders of the global polity, from the public and private sectors to academia and civil society." [2]

Technologically, the fourth industrial revolution on whose threshold we are currently standing arose from the microelectronics that characterised the third revolution. However, the extremely rapid development of storage media, processors, data transmission and display technologies, has resulted in new applications and services in the information and communications technology field.

This development thus forms the basis for a qualitative transformation that will bring about a new technical, societal, and not merely industrial, revolution. The heart of this revolution is the digitisation, collection, storage and analysis of data relating to individuals, objects and systems, be this data societal, physical or biological, for the purpose of influencing, controlling and optimising it in pursuit of a specified objective.

The goal of Industrie 4.0 is to harness this immense innovation potential for industrial production and, in particular, German industry.

"... the introduction of the Internet of Things and services into the manufacturing environment is ushering in a fourth industrial revolution. In the future, businesses will establish global networks that incorporate their machinery, warehousing systems and production facilities in the shape of Cyber-Physical Systems (CPS). In the manufacturing environment, these Cyber-Physical Systems comprise smart machines, storage systems and production facilities capable of autonomously exchanging information, triggering actions and controlling each other independently. This facilitates fundamental improvements to the industrial processes involved in manufacturing, engineering, material usage and supply chain and life cycle management. The smart factories that are already beginning to appear employ a completely new approach to production. Smart products are uniquely identifiable, may be located at all times and know their own history, current status and alternative routes to achieving their target state. The embedded manufacturing systems are vertically networked with business processes within factories and enterprises and horizontally connected to dispersed value networks that can be managed in real time – from the moment an order is placed right through to outbound logistics. In addition, they both enable and require end-to-end engineering across the entire value chain." [3]

The physical and virtual worlds are converging, which is also changing the business relationships and value creation chains at companies. This digital transformation in the business world is causing changes that bring with them opportunities and risks. Digitisation will be accompanied by far-reaching challenges such as new business models and flexible company processes. Here, digital transformation is the key to successfully meeting the increasing complexity with shorter delivery times and individualisation of products. The optimisation of production processes is continuously being enhanced with artificial intelligence and self-learning systems. These self-learning systems in turn require the support of Manufacturing Operations Management (MOM) systems.

The technical developments that will boost innovation in the area of Industrie 4.0 include the following:

1. The possibility to cheaply equip physical objects with computing power, storage capacity, sensors and communications interfaces – smart objects and cyber-physical systems
2. The possibility to use these objects to communicate via digital networks that span the globe – (Industrial) Internet of Things/(I)IoT
3. The possibility to save and provide data and computing power in distributed systems – cloud computing
4. The possibility to save and analyse large data volumes – big data and algorithms
5. The possibility to access distributed functionalities through services – service-oriented architecture (SOA), Internet of services
6. The possibility to communicate with people via digital communications structures and means – smartphones, data glasses, social networks, virtual reality
7. The possibility to promote artificial intelligence and integrate it into existing production processes

Fig. 1: Social and economic challenges

Source: iTAC Software

2.2 Plattform Industrie 4.0: defined goals

However, the technical side should not be our sole focus in the context of Industrie 4.0. This development is taking place in a globalised world and, at least in the highly developed countries, has further challenges to overcome as shown in Figure 1.

This is compounded by increasingly scarce resources and energy, which make greater efficiency, productivity and quality seem more important than ever.

In technical terms, Industrie 4.0 comprises digitisation with the aim of fully networked production. Consistency of the information along the value creation chain in all directions is the key aspect here. In this context, the following eight goals have been defined by Plattform Industrie 4.0:

1. Standardisation
   Open standards for a reference architecture enable cross-company networking and integration across value creation networks

2. Managing complex systems
   The use of models for automating tasks and integrating the digital and real world

3. Delivering a comprehensive broadband infrastructure for industry
   Ensuring that the data exchange requirements relating to volumes, quality and time are met in the scope of Industrie 4.0

4. Safety and security
   The aim here is to ensure operational safety, data privacy and IT security

5. Work organisation and work design
   Clarifying the implications for people and employees as planners and decision-makers in Industrie 4.0 scenarios

6. Training and continuing professional development
   Formulating the contents as well as innovative approaches for training and continuing professional development

7. Regulatory framework
   The objective is to create the required – Europe-wide, if possible – regulatory framework for Industrie 4.0 (protection of digital goods, contract law for contracts concluded between systems, liability issues, etc.)

8. Resource efficiency
   Responsible handling of all resources (human resources and financial resources as well as raw materials, agents and operating fluids) as a success factor for future industrial production

The path to Industrie 4.0 is an evolutionary process. The existing basic technology needs to be developed further and standardised if we are to succeed in optimising the entire value creation chain.

3 From MES to Digitised Manufacturing Operations Management

What role will manufacturing execution systems play under Industrie 4.0 or smart manufacturing, as it is known outside German-speaking regions, in the future? The answers to this question range from "none because the hierarchical structure of PCS, MES, ERP will be dissolved" and "less and less of a role because it will be cannibalised by enhanced PCS and ERP functions" right up to "a central role because MES will form the crucial link to the organisation of an optimal value creation chain".

If we take the business objective of Industrie 4.0 as a guide, it quickly becomes clear that the "ability to derive the best possible value stream from data at all times" requires greater flexibility, dynamism and functionality than today's manufacturing execution systems provide with their traditional focus on execution management.

The solutions on offer in the area of MES will have to be developed further until they provide comprehensive manufacturing operations management (MOM), that is capable of organising the "best possible value stream" while taking into account all the aspects of manufacturing operations management. Given the complexity of this task and the possibilities of information and communication technologies, the current monolithic systems will have to be reconsidered. The trend that is recognisable today is towards solutions in a collaborative interplay of the various modular components and functions of manufacturing operations management.

3.1 Manufacturing execution systems

Despite the aforementioned pressure for advancement, today's manufacturing execution systems continue to have a role to play, as they already provide partial aspects and information, particularly in the area of production operations management, that should not be overlooked.

For a definition of the tasks of MES, please refer to the following publications from various associations and organisations:

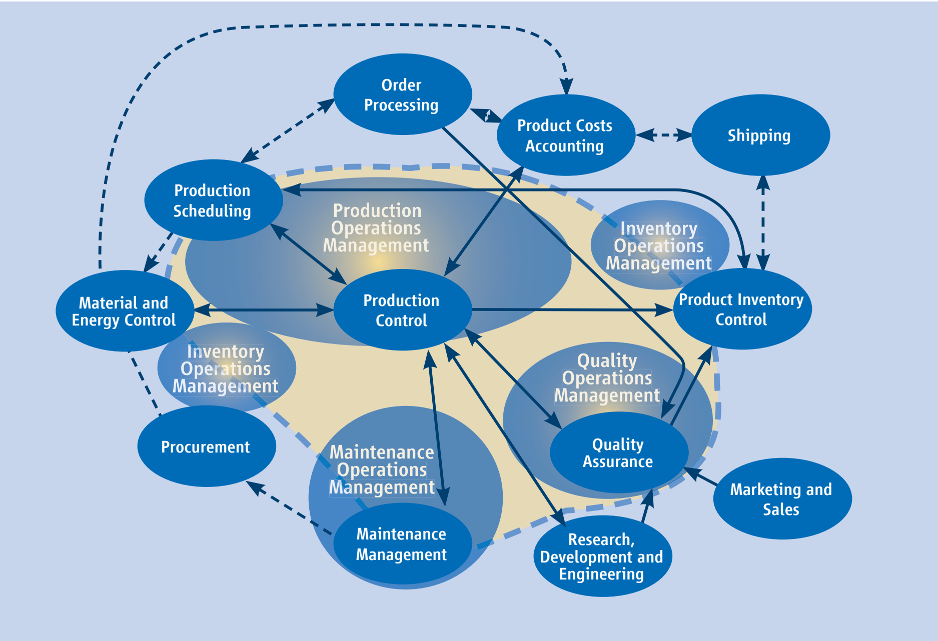
- IEC/EN 62264, Enterprise control system integration
- VDI directive 5600, Manufacturing Execution Systems (MES)
- VDMA standard sheet 66412-10, Manufacturing Execution Systems – Data for Production Indicators
- Namur worksheet 94, MES: Functions and Examples of Operations Control Level Solutions

Information regarding how and in which form MES can improve the various aspects of production is provided in the 2010 brochure from the ZVEI MES working group: "MES – Industry specific Requirements and Solutions " [4], which remains valid.

3.2 Manufacturing operations management in accordance with IEC/EN 62264

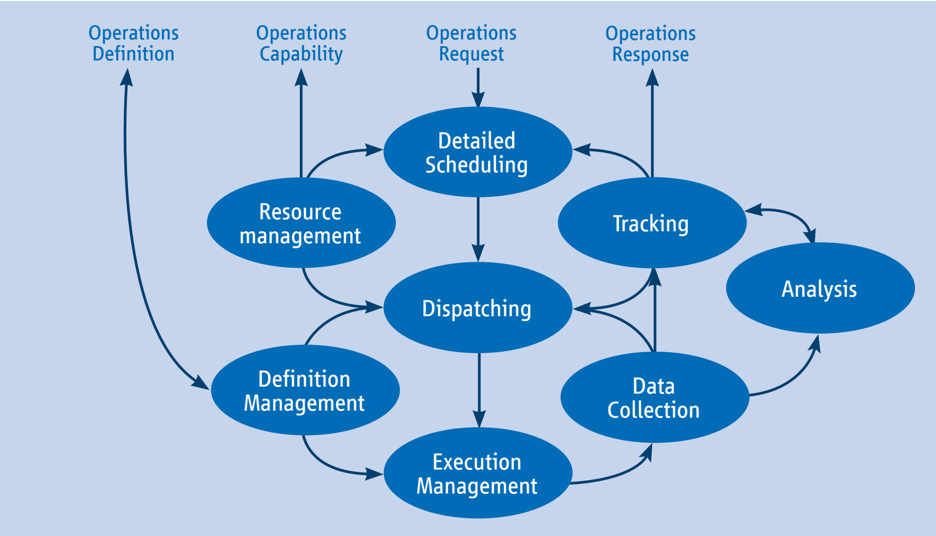
Despite the significance and benefits of MES today, the future development towards

Fig. 2: Functional model from IEC/EN 62264



Source: ZVEI, based on IEC/EN 62264

Fig. 3: Generic activities model from IEC/EN 62264



Source: ZVEI, based on IEC/EN 62264

comprehensive operations management that meets the requirements of Industrie 4.0 should be aligned to IEC/IEN 62264, which covers all areas of operations management.

This standard identifies a total of twelve functions that must be assigned in manufacturing operations (see light blue ovals in Figure 2). Six of these functions can be found in the area of manufacturing operations management (MOM) (highlighted in yellow) and are sub-divided into production, inventory, quality and maintenance operations management (see dark blue oval in Figure 2).

Within these areas, the standard defines the activities presented in Figure 3 with their models, attributes and the required exchange of data within the areas.

In addition, information needs to be exchanged between the activities in the production, warehouse and inventory, maintenance, and quality areas, and this is also defined in the standard.

IEC/EN 62264 thus provides an appropriate basis for the manufacturing operations management required under Industrie 4.0.

This definition of manufacturing operations management will not become superfluous as a result of Industrie 4.0

On the contrary: Industrie 4.0 will not be possible without digitised manufacturing operations management. Without digitalised manufacturing operations management, the new stage in the organisation and control of the entire value stream will not be achieved. Whether the systems, algorithms, services and transactions required for this will continue to operate under the term "manufacturing execution systems" (MES) or the term will then be "manufacturing operations management" (MOM) is unimportant. The functions of MES are still required and must also be implemented and enhanced in an Industrie 4.0 compatible manner..

We aim to show the nature of these changes in the remainder of this paper.

3.3 Foreseeable developments of MES under Industrie 4.0

The manufacturing execution systems in use today will undergo a transformation towards manufacturing operations management (MOM) in the context of Industrie 4.0. It can be assumed that, during the course of the transformation, increasingly modular manufacturing execution systems will appear on the market in the future. The focus will move away from horizontal or vertical system integration and towards multi-disciplined (business) process integration. In practice, it will not be possible to perform this multi-disciplined integration using a monolithic software system. Instead, the only option will be smooth interaction between various partial systems that will together make up a manufacturing company's individual MOM. The components of these systems will need to be matched up to one another to ensure that system gaps and mismatches can be avoided.

In the scope of Industrie 4.0, it is not sufficient to simply exchange data records between systems.

In the future, the way systems work together will be much more interactive. Interpretation of the exchanged data will be necessary (consistent semantics).

To achieve this, today's manufacturing execution systems will have to expand their horizons beyond the shop floor and generate valuable information from all available data, for example using big data techniques. This development will also make advanced data exchange with ERP systems even more important than it is today. This data can be used to determine KPIs that provide an indication of where there is room for improvement and thus necessitate enhanced and more flexible analytics.

If these KPIs from the operational manufacturing process are combined with the up-to-date process-related data that will be made available in the course of Industrie 4.0 and with the possibilities of big data techniques, new, multi-disciplinary information can be acquired. In this process, we could, for example, recognise dependencies between the energy consumed by a pump motor and the product quality, allowing us to draw conclusions regarding the wear of the pump.

Countless questions and tasks are possible here that all have one thing in common. They can only be posed if:
– The database is large enough
– The analysis methods are available
– They are answered across disciplines
– The necessary conclusions are drawn
– The insights gained are incorporated into live operation

In this context, manufacturing execution systems in their current implementation form the basis of the future MOM. During the course of the transformation to MOM, changes will occur in a wide range of areas. Some of these changes are described below.

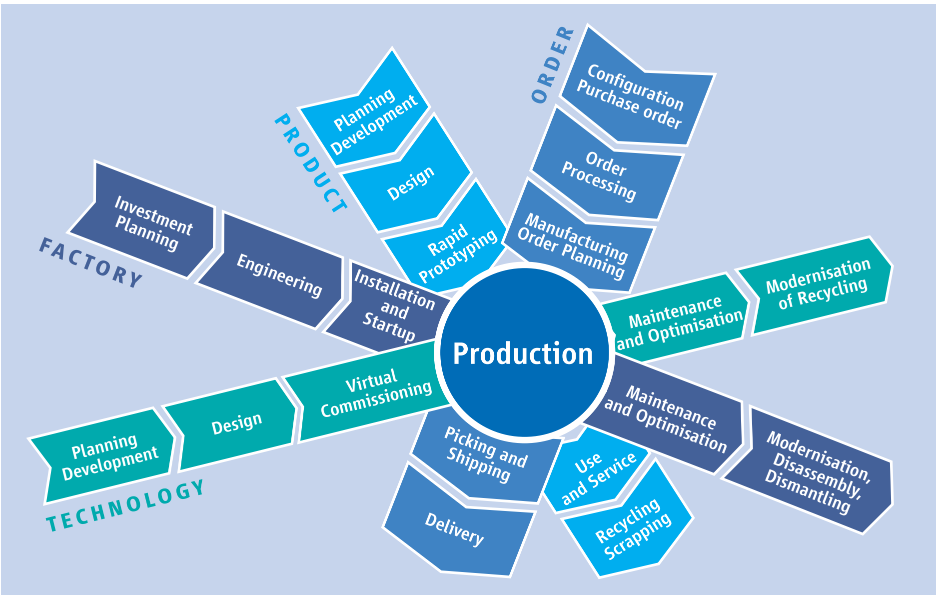
3.3.1 Consistency and enhancement of data

One of the key objectives of Industrie 4.0 is the availability of all relevant data throughout the entire lifecycle of a product. For this reason, in the future MOM solutions will need to use all data that is enhanced before the actual production stage as well as pass all data that is generated or recorded during production on to the following links in the value creation chain, as shown in Figure 4.

3.3.2 Overcoming organisational structures

Organisational corporate structures that have evolved over many years – with areas of department responsibility and the corresponding IT infrastructures growing alongside them – and have been aligned to organisational units will undergo significant changes. Within the areas of responsibility that grew up, software and management systems emerged for segregated tasks. These will be replaced under smart manufacturing and Industrie 4.0 considerations, as here increased collaboration is the focus and the areas of department responsibility

Fig. 4: The four life cycles in industrial manufacturing



Source: Based on ARC

no longer need to be clearly separated. Smart manufacturing and Industrie 4.0 address the highly granular structuring and modularisation of manufacturing plants. This process is expected to proceed rapidly and will also require the dissolution of organisational structures. manufacturing operations management systems must therefore behave as "mediators" between the modularised, dynamically adaptable production infrastructure and the organisational structures.

3.3.3 New services and business models

Another foreseeable development is the formation of new business models in the area of manufacturing operations management that will function as services for further optimisation of process flows and costs.

The reconsideration of business perspectives means that every company must consider in relation to the new possibilities which changes and challenges it will face in the future. As a result of the digitisation of processes, company structures and organisations will become quicker to modify and yet still be controllable, new partnership models will become possible and production processes across multiple production locations and companies will be simplified. The creation of suitable conditions for the production of components and the associated processes will be simplified and accelerated, which will lead to the further development of a sphere based on the division of labour (e.g. manufacturing as a service models, the use of shared components, cross-manufacturer processes, etc.).

The "enforcing" (executive) and "planning" management in production will face new requirements. The elementary functions of an MES will be retained; however, future MES will need to be structured in a modular way, in the sense of MOM, and be aligned to the functions in accordance with IEC 62264.

3.3.4 MES, MOM and big data

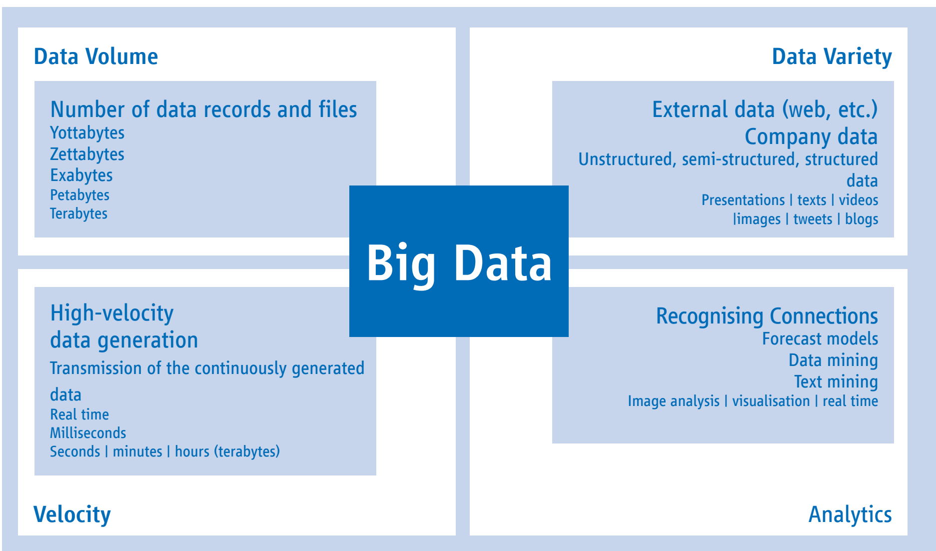
From today's perspective, the majority of production managers are still sceptical of "big data". They believe that data should be collected and archived if one has a use for it or is obligated to generate evidence. Big data analyses like those that are performed in social networks or the field of consumer behaviour remain largely foreign in manufacturing.

In the Bitkom guide [5], the term "big data" is described as follows: "Big data supports the economically viable collection and use of relevant decision-making insights from qualitatively varied and differently structured information that changes rapidly and is available in a previously unprecedented quantity."

The following Figure, which can also be found in the guide, illustrates this.

The technical developments presented here are enormously beneficial for big data (cheap and large data memory, networking, data consistency, etc.). This allows procedures and methods that we are familiar with from big data to also be used for production. One of the key features here is that we cannot determine today which data will be required in relation to a specific investigation or will be relevant in the future. Thus even producing companies have the task

Fig. 5: Properties of big data



Source: Bitkom

Table 1: Business benefits of big data arrangements

Business benefits	Explanation
Decisions/risk assessment	With big data, decision-making bases can be improved and risk assessments made easier.
Process optimisation	More detailed analysis of internal and external data can contribute to optimised business processes and reduced costs.
Profitability	Sales and requirements planning with the support of big data guarantees delivery capability, prevents lost revenue, and thus increases profitability.
Pricing	Big data analyses provide the (previously not really possible) option to adapt prices to the current market situation in real time.
Customer focus/potential exploitation	Big data analyses make it easier to align offers with the specific characteristics of customers (customer groups) and to detect gaps in the market.

Source: Bitkom

of collecting as much data as possible, although the purpose is as yet unknown, and archiving it in a way that allows as many relationships as possible to be established (temporal, production facilities, suppliers, production conditions, etc.).

Big Data affects MES and MOM in at least two ways:

- They are suppliers of data and thus need to be integrated into big data concepts as data sources.
- They are recipients of information that is gained from big data analyses.

MES and MOM implement the planning and optimisation tasks shown under "Decisions/ risk assessment", "Process optimisation" and "Profitability" in the table above.

3.3.5 Typical process environments for MES and MOM

3.3.5.1 Central tasks

Production procedures in accordance with Industrie 4.0 (I4.0) will also involve a host of tasks that cover the entire manufacturing process, centrally and across manufacturing areas. These include, for example:

- Higher-level tasks (rough planning of manufacturing orders and resource availability), but with dynamic feedback regarding the current resource situation
- Key performance indicators (KPI) affecting the whole of production
- Archiving of production data (centrally or decentrally but with a central analytical approach (assigned to the products/orders in question))
  - To meet legal requirements
  - To ensure traceability in the event that quality issues arise
- Manufacturing-wide or company-wide collection of quality data (possibly already provided in compressed form by decentral units)

3.3.5.2 Decentral tasks

In the future, there will be tasks under I4.0 that are organised in a more decentral way. These include, for example:

- MES functions in the sense of line management As a result of this, it will be possible for MES hierarchies to form that need to communicate with one another and exchange data.
- KPI calculation across lines or for individual machines/apparatus
- Flexible planning of (partial) orders taking into account local resource availabilities
- Quality data recording, compression and provision for higher-level systems
- Incorporation of service orders and consideration by the MES regarding when at the latest an order (manufacturing and service) should be completed

3.3.5.3 Coordination of tasks

In production, management execution systems serve both as a link between the ERP systems and the physical manufacturing (vertical coordination) and as a link between the individual units that are performing the manufacturing process as well as coordinating accompanying functions such as maintenance (horizontal coordination).

Vertical coordination

The MES takes on a manufacturing order triggered by the ERP system and controls it at manufacturing level (shop floor) until it is completed. While the ERP system plans, coordinates and schedules orders amongst themselves (e.g. by assigning start/end dates), the MES has a control task within the processing of the individual orders.

Here, the MES not only ensures an end-to-end data flow from the ERP system up to manufacturing, but also reports both partial steps and completed orders back to the ERP system. This feedback allows the ERP system to build its order planning on real-time data rather than calculating on the basis of planned data or capacities. This allows the ERP system to assign orders taking account of information that is collected at the current requirement time (e.g. current process status or condition of the tool magazines of individual machines).

Horizontal coordination

In the scope of horizontal coordination, the machines are networked in terms of information by the MES. A key task here is to provide the required interfaces to enable communication between machines that currently often still work with proprietary data formats. The direct transfer of the machine data means media discontinuities as well as time-consuming and potentially faulty, sometimes repeating, manual tasks can be avoided.

3.3.5.4 Dynamic execution management

Making operating processes flexible is a key component of a digital equipping workflow in manufacturing. This is explained based on the example of discrete manufacturing. The transformation of traditional rigid processes into dynamic processes is a component of the digitisation strategy.

- All systems whose processes are clearly and predictably defined based on preconditions are referred to as "rigid".
- The term "dynamic" is used to refer to all systems that automatically adjust their preconditions to a new situation.

To show the distinction of "rigid versus dynamic", here we use the example of the "provision of tools" activity in discrete manufacturing.

Practical example [6]:

Initial situation:

Tooling machines require a wide range of different tools to machine the parts and have a tool magazine for this purpose. On average, tool magazines have a capacity of between 20 and 200 tools. The term "net tool requirement" is used in the equipping process and can be understood as follows:

Rigid solution:

A specialist department decides which different parts are to be manufactured on a machine and how many and which tools are loaded into the tool magazine as standard on this machine for this purpose and remain there permanently.

Example: A tool magazine with a total of 120 spaces is loaded with the 80 tools that are considered to be the most frequently used. The remaining 40 spaces are left free so that job-specific special tools can be added later. These special tools must be removed again as soon as the job is finished to make room for the special tools for the next job.

Dynamic solution:

The ideal solution is a dynamic tool quantity calculation, which works as follows:

A new machine is brought into the company. The tool magazine is left empty. The first job with the first NC program is triggered via the PSP/ERP system. An MES scans the NC program and finds all the tool ID numbers. The MES now connects automatically to the tooling machine, reads out the tool magazine online (while the machine is producing) and can thus calculate the missing tools and request them from tool provisioning just in time.

Each additional job with a new NC program is executed in this way.

The dynamic tool quantity requirement calculation automatically detects which tools are in the magazine and only the missing tools are ordered. In this way, the tool magazine is automatically filled step by step with precisely the right tools.

After some time, the tool magazine is full and any tools that may be required for the subsequent work process can no longer be loaded. The MES now uses the job horizon in the ERP system and any remaining tool lives to calculate the required quantity of tools that can be unloaded preferentially.

The benefits of this dynamic solution:

Thanks to the intelligent loading and unloading strategy, the tool magazine adjusts to an ideal situation without the need for any "manual" decisions regarding which tools are to be loaded or unloaded. Dynamically recorded wear and potentially required repairs are also observed and taken into account for this.

Practical example [6]:

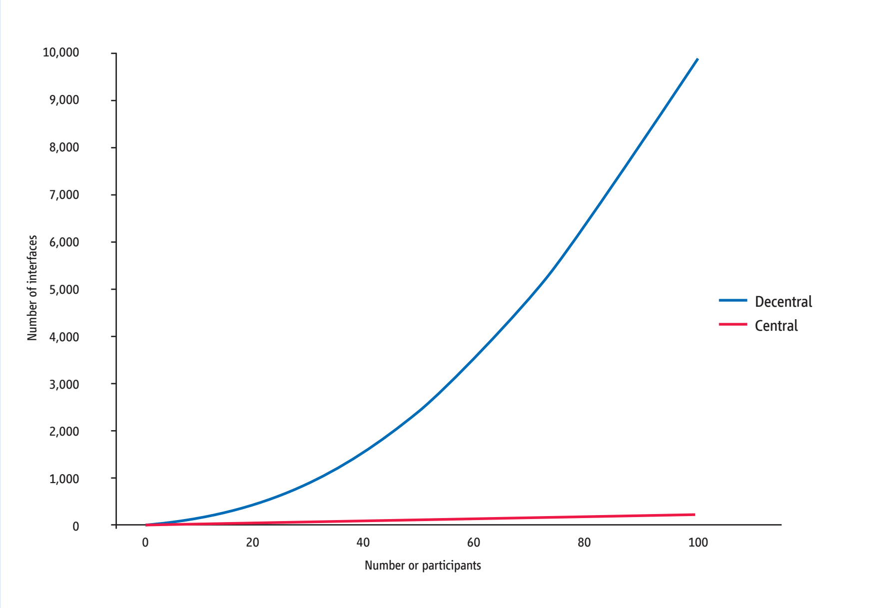
The price that still needs to be paid today due to the individual interfaces that are common on the market is numerous communication problems and the resulting costs..

The number of interfaces (I) in decentrally organised communication between the participants (n) is described using the following formula: I(n) = n (n-1)

Communication that takes place centrally considerably reduces the number of interfaces, as only two interfaces are required for each additional participant. The number of interfaces in centrally organised communication between n participants is thus always: I(n) = 2 n

In the context of Industrie 4.0, too, an MES will be a central data hub that will significantly reduce the number of required interfaces and make costs manageable.

Fig. 6: Number of interfaces I(n) in decentral and central communication



Source: Maschinenfabrik Reinhausen

3.3.6 Production management

In the area of specification management:

In the future, new specifications will no longer be created manually in manufacturing specifications, production plans or recipes in the MES, but will be added as digital data from the upstream systems (e.g. research and development) and linked with data from resource management regarding production units and their capabilities to form execution specifications.

During the course of product specification outside their own company and the individualisation of products (lot size 1) that are, for example, configured by the buyers themselves or specified and electronically transmitted by the ordering company, the definition management must be able to determine whether the product can be produced using the available resources and their capabilities and supply this information to the ERP as part of the order confirmation.

In the area of resource management:

Employees: The required qualifications and availability of employees will be checked and confirmed with system support by comparing the production-related data with data in the personnel information system. If necessary, requests will be created.

Equipment: To ensure that the required machines and systems are available, access is automatically provided to all production-related data such as the current technical and operating condition, planned maintenance and calibration, current and planned use and other information.

Material: The required material is determined with regard to the current and foreseen stock (confirmed delivery date, planned quantities) and allocated accordingly.

In the area of detailed scheduling:

Dynamic planning and optimisation procedures determine when machines, systems, installation sites, etc. are in use taking into account ancillary conditions such as optimum value creation, minimisation of costs, economic availability of resources, scheduled delivery dates, quality to be achieved, etc.

In the area of dispatching:
The values determined during detailed scheduling are digitised and sent to the manufacturing facilities in the form of equipping and manufacturing orders.

In the area of execution management:
The production activities are dynamised through the previous stages of detailed scheduling and dispatching, and rigid, predefined tasks and processes are replaced with dynamic task management, operator guidance for support tasks and troubleshooting in a highly automated production and manufacturing facility.

In the area of data collection:
Every production process and manufacturing step is accompanied by constant collection of production-related data. In this process, the "completion message" that is common today is correlated with the collected data, which is then analysed for optimisation, quality and evidence purposes.

In the area of analysis:
The analysis procedures will be transformed in that they are no longer used at a later stage in laboratories or testing facilities, but online and alongside the production process. This allows the results of the analyses to be immediately linked back to the production process. This is an essential prerequisite en route to MOM.

In the area of tacking:
The MOM tracks the flexible processes and their related events as well as the changed sequences in dynamic executions, detailed plans and scheduling, meaning that, for the piece number, it is still possible to seamlessly track and trace the routes, resources used, required analyses and data for increased quality assurance of the individual manufacturing process and the individual product.

One of the visions of Industrie 4.0 or the digital actory is a self-organising production process. Even if we were to follow this vision precisely, we would discover that planning tasks and the reporting prescribed by operators and legislators cannot be avoided. MES and MOM have played a significant role here until now, and will continue to do so in the future.

3.3.7 Warehouse and inventory management

Developments in warehouse and inventory management are being driven by the use of modern information systems (cloud technologies, IoT, big data, etc.). The warehouse will evolve into an intelligent warehouse right down to item level. Cyber-physical systems that communicate via the Internet of Things are the core component for warehouse design and the optimisation of warehouse processes and intralogistics.

Automated orders are likely to become the rule with Industrie 4.0. This is only possible if a warehouse and an inventory are precisely and fully mapped through the corresponding data and demand or planned preventative maintenance are dynamically taken into consideration.

Close interaction between production, planning and intralogistics is essential for production-synchronised procurement and warehouse-free (just in time) material supply.

3.3.8 Maintenance management

High machine availability is a critical success factor for producing companies. Unexpected downtimes generate high costs as a result of unplanned maintenance tasks that can only be achieved with a great deal of effort.

I4.0-optimised machines and systems will generate ever increasing data quantities. A key task will be to not only collect this data and make it available to business partners and plant engineers via the cloud, but also to use the information in a profitable and cost-reducing manner. Analytical processes will be required to gain valuable insights for preventative dynamic measures from the generated data.

All data that is relevant for up-to-date, dynamic maintenance must be used as a basis for more efficient planning of future production and production optimisation processes.

One scenario that can be foreseen is that a machine continuously collects data regarding its current condition using suitable sensors, simultaneously considers past downtimes and their causes, and, based on this, provides information regarding when maintenance will be needed in good time before it fails. Any required consumables and replacement parts are automatically ordered or provided for the maintenance date in coordination with the dynamically adjusted production plan.

3.3.9 Quality management

As well as the increasingly complex production processes, legislators and continuously developing consumer protection will make constant, targeted monitoring of product quality necessary in the future. This is the only way that unexpected changes in the product's properties can be detected immediately and countermeasures implemented. The quality processes will become dynamic in this area, too. For example, on the basis of online and inline analyses and their data, changing quality requirements will be recorded, evaluated and returned to the production department in the form of measures to be taken. In this way, closed quality control loops can be created with the aim of achieving the best possible quality of products and production procedures.

Complex measurement strategies and analyses provide the actual values regarding the process quality, which can then be incorporated into the production-related control loops. This enables production planning and control to respond to both "in-line" and "on-line" quality changes.

4 Manufacturing Operations Management in the Context of RAMI4.0

The Reference Architecture Model Industrie 4.0 (RAMI4.0) [7] has evolved into a significant architecture model for I4.0. Not only has it been observed in standardisation work, but many international committees have also used it as a guide. This section will start by classifying Manufacturing Operations Management in RAMI4.0. We will then look forward to the upcoming work in the direction of an I4.0 asset administration shell.

4.1 Classification of manufacturing operations management in the Reference Architecture Model Industrie 4.0 (RAMI4.0)

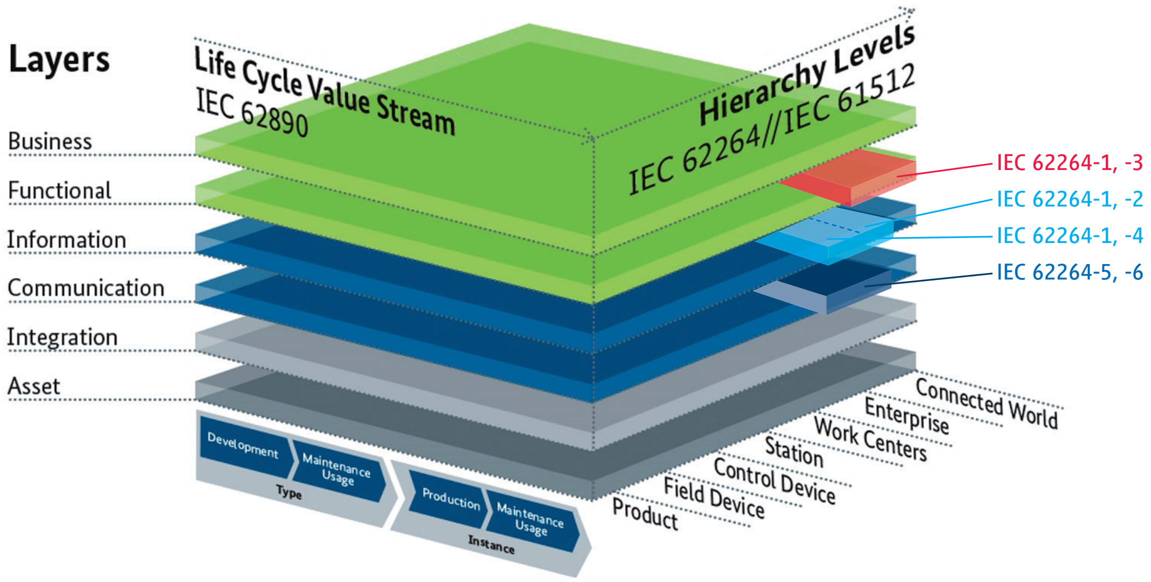
The Reference Architecture Model Industrie 4.0 (RAMI4.0) was developed to allow various aspects of assets to be classified and described. As can be seen in Figure 7, it has three axes.

- Architectural axis (layers) with six levels to map the relevant information for the asset's role
- Progress axis (life cycle and value stream) to show the lifecycle of an asset and the value creation process on the basis of IEC 62890
- Hierarchy axis for allocating functional models to the individual layers on the basis of the standards DIN EN 62264-1 and DIN EN 61512-1

Manufacturing operations management can be positioned in the context of Industrie 4.0 (Figure 7) by classifying the individual components of IEC 62264 within RAMI. Here, there are basic models in part 1 that were used to define the hierarchy axis and that recommend a general classification of the traditional scope of MES into the levels "Station", "Work Centres" and "Enterprise". With regard to the progress axis, the "Maintenance/Usage" time domain of the instances is currently addressed, which corresponds to the term "manufacturing operations". The engineering of an MES solution is to be allocated to the "Production" time domain, while considerations regarding the development and maintenance of MES components are assigned to the time domains of the type.

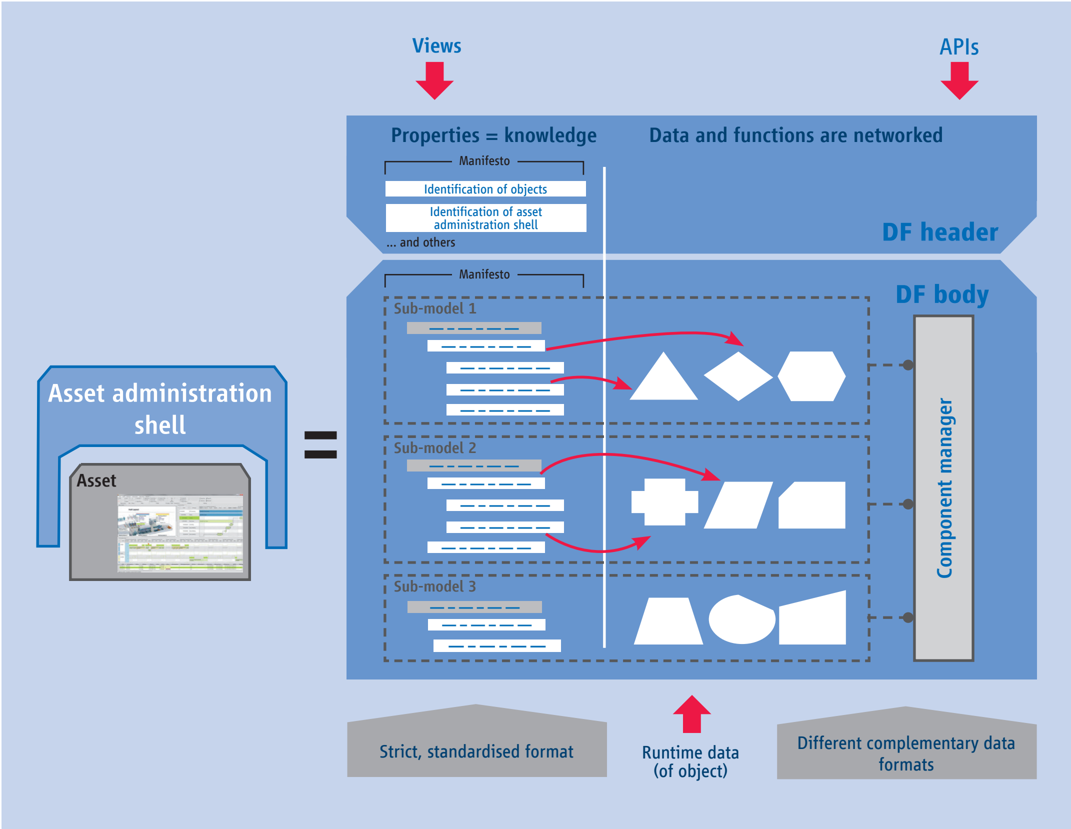
The individual attributes of the object models can be allocated to the "Information Layer" aspect, whereby part 2 covers the "Enterprise" level and part 4 the "Work Centres" level. The activity models defined in part 3 are given a functional description, meaning they can be allocated to the "Functional Layer" aspect. Finally, part 5 describes transactions that can be used as a basis for Industrie 4.0 MES services and therefore address the "Communication Layer". The specific IT-based implementation of the components in an MES solution can be assigned to the "Integration Layer" (supporting functions) and "Asset Layer" (the hardware and software itself).

Fig. 7: Principal classification of MES in RAMI4.0 on the basis of IEC 62264



Quelle: Automation 2015 [8] – extended

Fig. 8: Asset administration shell for an Industrie 4.0 component



Source: ZVEI and Plattform Industrie 4.0 [9]

4.2 Industrie 4.0 components and their asset administration shells

An asset is understood to be an object that has a value in relation to Industrie 4.0 and is used in an Industrie 4.0 context. Whether the object exists in the physical world or the information world is irrelevant here. An asset is represented by an Industrie 4.0 component. This consists of the asset itself and an asset administration shell (Figure 8) and can be reached using Industrie 4.0-compliant services. The Asset Administration Shell (AAS) contains the relevant information to represent the asset including its technical functionality. It provides the information structured in accordance with RAMI4.0 regarding the asset or several assets to the information world. The asset administration shells do not have to be stored on the asset itself.

According to DIN Spec 91345 [7], an asset administration shell is divided into a header and a body. The division into a header and a body follows the specifications of IEC/TS 62832-1 [10].

The specific properties of the asset are contained in sub-models. The individual sub-models should include specific properties and technical functionalities for an area of application. The features are preferably mapped by means of properties in accordance with IEC 61360, with Industrie 4.0 services providing access to the properties and the technical functionality. Properties of this type are used, for example, in eCl@ss and in the context of standardisation activities for the digital factory.

4.3 Collaborative manufacturing operations management with Industrie 4.0 components

In view of the anticipated increased flexibility in production, efficient operations management (MOM) solutions are becoming more and more significant for production control and optimisation from a business perspective. Functions-based and cross-organisation manufacturing operations management is required that responds dynamically to changes and is able to master the interaction between tasks, resources and changing requirements. Here, the functionalities that are defined in an abstract way in IEC 62264 and implemented in industry-specific solutions will form an excellent basis that can certainly be enhanced with new functions.

While the core functions will continue to be necessary due to the dynamically subordinated processes, their implementation will be distributed across the components of an Industrie 4.0 system and they will have to interact collaboratively. When it comes to implementation on the software side, solutions will therefore move away from monolithic software systems and towards functional modules that will be implemented in a highly distributed way as autonomous components or as integral parts of Industrie 4.0 components.

This requires a focus on functions and flexible deployment management. This kind of structure is beneficial due to its flexibility and solutions that are optimally tailored to the specific application case. A disadvantage is the increased communication effort.

The specific distribution of the functions across Industrie 4.0 components is difficult to generalise. Here, the abstract description in IEC 62264 provides an opportunity to create a kind of building block system for operations management functions based on best-practice templates or industry standards. In the future, it will then be possible to implement these building blocks in components on the basis of models or following pragmatic concepts. Their interoperability is supported through the structural and partially semantic specifications of IEC 62264 in that this serves as a basis for the sub-models of Industrie 4.0 MOM components.

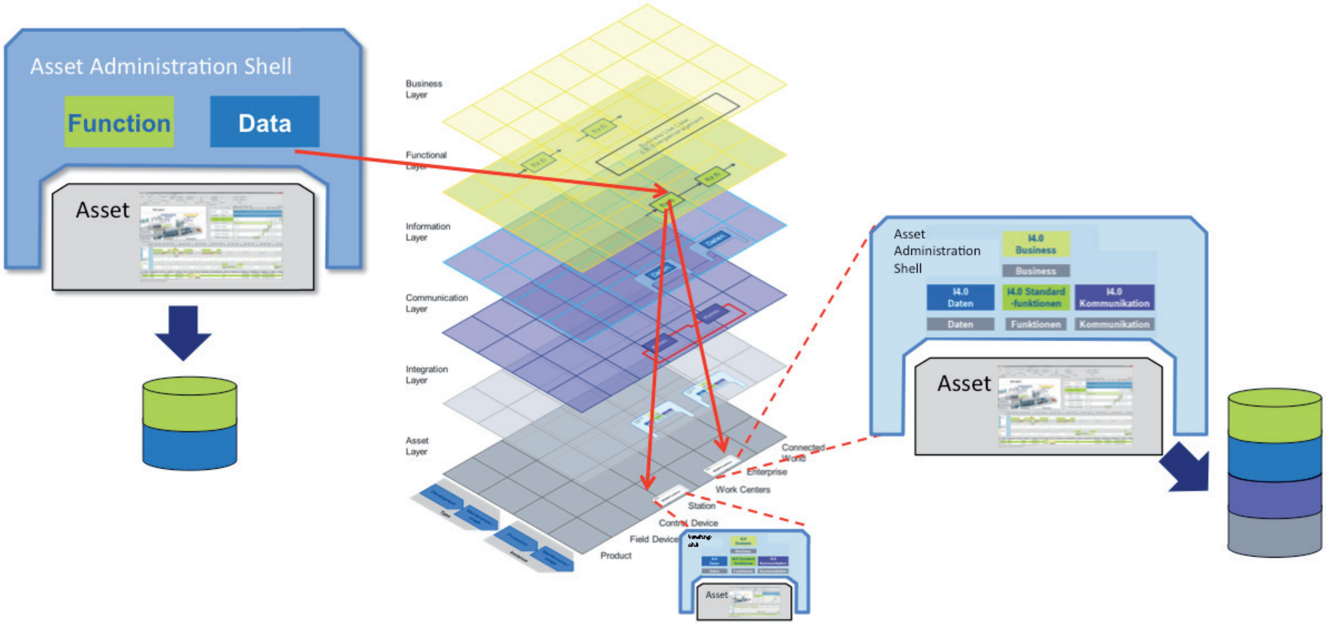
4.4 Development of submodels for Industrie 4.0 manufacturing operations management components

The basic functions of a MOM are described in IEC 62264-3. To transfer them to Industrie 4.0, they would have to be mapped as sub-models of the asset administration shell and be capable of communicating via an Industrie 4.0-compliant service system. For this, the functions are viewed as assets. The asset administration shell describes their features as properties (on the left of Figure 9), making them accessible to other I4.0 components based on services. Standardised data, which is defined in parts 1, 2 and 4 of IEC 62264, is also mapped and described semantically as properties based on its availability.

The implementation and distribution of the MOM functions on Industrie 4.0 components – be this as sub-functions of a component (e.g. machine) or as autonomous MOM components – adds further properties to the function and data features stored in the asset administration shells for these components. These describe, for example, the services provided with their communication properties in the Communication Layer of RAMI 4.0 and implementation details in the Integration Layer (on the right of Figure 9).

The interaction between the components is by means of service on the basis of Industrie 4.0-compliant communication. For this purpose, the Industrie 4.0 systems provide basic services (such as for read and write access to the asset administration shell) and platform services (e.g. for identification or for setting up interactions). For collaborative applications in the MOM or MES domains, however, it makes sense to provide domain-specific services that also include complex MOM functionalities for Industrie 4.0 communication. The 'Business to Manufacturing Transactions' from IEC 62264-5 form the basis for MOM services of this type. In addition, new potential added value services with rich sematic functionalities (e.g. for energy consumption management) can be realised.

Fig. 9: Functional view of the asset administration shell of an MOM component (left) that is enhanced with further features through implementation (right)



Source: ZVEI, MES working group

5 Summary

Without extensive digital operations management, Industrie 4.0's key goal of controlling an optimum value creation stream in production will not be possible. Specification and resource management, detailed scheduling, execution management, data collection, analysis and racking are indispensable components for this. An up-to-date overview of the current and planned status of production and the availability of required resources is essential in order to organise production optimally and to respond flexibly to changes such as a new order situation or disruptions in the production flow.

The significance of MES or MOM in Industrie 4.0 will therefore increase and not decrease. However, the focus will shift away from simple execution management towards comprehensive coverage of all MOM activities and away from control of production towards optimisation including incorporation of events.

The manufacturing operations management systems in use today for warehouse storage, manufacturing execution, laboratory information management and maintenance management fulfil partial aspects of the manufacturing operations management tasks. However, under Industrie 4.0 conditions these systems will have to develop in such a way that they can be combined interoperably as Industrie 4.0-compatible MOM components, without the effort that is currently required to program interfaces, to form an manufacturing operations management solution for the company in question. One can also picture future interaction between the ERP and manufacturing ooperations management level as communication between different I4.0 components without the need, for example, to replicate the master data from one level in the other level.

In the opinion of the ZVEI MES working group, future I4.0 manufacturing operations management solutions will be realised through the interaction between compatible I4.0 MOM components.

The necessary standardisation and definition of sub-models for MOM components for this is currently still in the early stages and will still need quite a bit of time. If an MES or MOM solution is required, currently and in the near future we recommend continuously observing the market and considering using the systems that are available on the market at present.

In the opinion of the ZVEI MES working group, separable and complementary sub-models should be defined for manufacturing operations management activities in the areas of production, warehouse, quality and maintenance.

The ZVEI MES working group intends to collaborate with working group AK931.0.2 "Unternehmensmodelle" (enterprise models) from the DKE (German Commission for Electrical, Electronic & Information Technologies of DIN and VDE) to define examples for such sub-models.

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