Automation

Manufacturing Execution Systems (MES)

Industry specific Requirements and Solutions

Automation

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Introduction and objectives

Numerous company or industry-specific software solutions and products have been developed to manage administration and organization of manufacturing processes. Although they are generally presented as MES (Manufacturing Execution System), the scope of these solutions ranges from „My Excel Sheet“ to comprehensive management, organization, and automated processing of all production-related processes.

This brochure is not another attempt to define the term Manufacturing Execution System. Rather, in issuing this brochure, the objective of the ZVEI Working Group „MES“ is to provide the interested reader and the professional audience with an overview of currently existing or feasible solutions which fulfill differing industry-specific requirements. The objective of this brochure is to promote the utilization of suitable MES applications for optimized production.

The working group has used the „Enterprise-Control Systems Integration – IEC 62264“ set of standards as a basis for product and vendor independent presentation of the functionality. Chapters 1 through 3 provide a short introduction to this standard which is also known as S95. Currently, different terminology for the same MES terms and tasks is used across industries and even among vendors. Therefore, Chapter 4 classifies the most important terms based on the S95 structure and terminology, providing guidance through the multitude of different terms and products.

Based on industry-typical requirements, chapter 5 presents the opportunities and benefits of MES functions. Chapter 6 explains the essential similarities and differences of MES applications in the process and manufacturing industry. Chapters 7 and 8 provide an outline of the requirement definition and the selection of MES functions, and present their benefits based on specific examples. Chapter 9 summarizes this brochure and presents an outlook on future MES solutions.

As presented in chapter 5, already today, comprehensive industry-specific solutions are available, which address the respective requirements by their scalability, modularity, and integration capability. These solutions can contribute significantly to improving the operational excellence of an enterprise.

The industrial operators are challenged to maximize this opportunity.

1 Market requirements and reasons for using MES

In order to evaluate the state of the art and the development of MES solutions, the place of MES in the history of automation must be considered. Today's MES solutions include former CIM components such as CAP (Computer Aided Planning), CAM (Computer Aided Manufacturing), CAQ (Computer Aided Quality Assurance), PDA (Production Data Acquisition), MDA (Machine Data Acquisition), and PTR / T&A (Personnel Time Recording, Time & Attendance).

However, these CIM components were not thoroughly integrated into the corporate processes. Instead, they were mostly used as single purpose applications on department level. Due to increasing corporate integration as well as better understanding of internal and external value chains, more integrated software solutions were required in order to better support manufacturing companies.

For these reasons, comprehensive MES solutions are increasingly used and recognized by the process and manufacturing industries. This trend is accelerated by the ongoing economic globalization which requires maximized competitiveness. The following goals must be accomplished:

- Improving productivity factors while increasing flexibility
- Higher production process efficiency
- Enhancing and ensuring process and product quality
- Overall process and cost optimization
- Shortening of product life cycles

The driving forces for using MES are new production-related developments, new production and logistic concepts as well as changed products and product development processes.

Product life cycles continue to shorten while the technological complexity of products increases. At the same time, development time is reduced, more prototypes are required, and more product variants are demanded.

In a global and competitive economy, „time to market" is a critical and deciding factor for the success of any manufacturer. MES can contribute significantly to that success.

The sustained improvement of the corporate value chain within the context of the requirements listed above calls for a set of tools which not only supports individual departments but considers „the production" as a holistic process within the enterprise.

MES implements this process as a real-time application. Since every aspect of the entire production is controlled in terms of this holistic process, sustainable improvement and optimization are attainable.

The real-time capability of MES spans multiple interdisciplinary requirements (such as order planning and control, material management, PDA, MDC, quality management, and document management) and provides a direct connection with the production process.

Furthermore, integration of the extended supply chain and global procurement as well as the regional corporate sales presence in developing markets is required.

MES is not only the operational link between „production" and „enterprise" but also links all partners within the supply chain. This enables a continuous, holistic, and manageable value stream.

On this basis, MES is emerging as a strategic element for flexible and integrated production. A MES combines all tasks of modern production management in a comprehensive software system for today. At the same time, this system is the operational platform for any enterprise evolving towards the „digital factory" of the future.

2 MES and normative standards (VDI 5600 / IEC 62264)

As indicated in the introduction, the term MES generally represents industry-, company- or vendor-specific solutions for the management of a production operation.

The VDI Guideline 5600 „Manufacturing Execution Systems" [1] generally categorizes MES in the area of discrete manufacturing as a „process-oriented manufacturing management system" and as the „comprehensive driving force for the organization and execution of the production process", with the following major tasks:

a) Organization and support of all activities related to the production process:
- Process requirements (order processing, resource planning, quality requirements)
- Operational actions (ensuring the availability of resources, flow of material, and quality)
- Tracking and analysis (inventory control; calculation of Key Performance Indicators; basis for Continuous Improvement Processes such as SixSigma and Operational Expenditure OpEx).

b) Implementation of the closed loop of all actions related to the execution of the production processes (planning, initiation, managing, controlling, documentation, evaluation, review, etc.).

c) Exchange of information with other levels such as corporate management (Enterprise Resource Planning, ERP) and the manufacturing / process levels, as well as operational support systems, for example Product and Process Engineering (P / PE), Supply Chain Management (SCM).

In compliance with VDI guideline 5600, the functionality of MES covers all chronological aspects of production processes:

Prognostic aspect → Planning of the production processes
Real-time aspect → Management of the production processes
Historical aspect → Analysis and evaluation of the production processes

The ZVEI MES working group uses the term MES as defined in the VDI guideline 5600 and as a synonym for all solutions and systems specified in level 3 „Manufacturing Operations and Controls" of IEC 62264. At the same time, some other terms like „Manufacturing Operations Management (MOM)" or „Collaborative Production Management (CPM)" are currently being used in the marketplace, which seek to emphasize the comprehensiveness of the task.

This brochure is based on the IEC 62264 „Enterprise-Control System Integration" set of standards, which is also published under the title DIN EN 62264 and consists of several parts. The three parts „Models and Terminology" [2], „Object Model Attributes" [3] and „Activity Models of Manufacturing Operations Management" [4] will be the main focus.

IEC 62264 defines the functional hierarchy levels of an enterprise, in which decisions with differing timescales and varying levels of detail must be made. These decisions depend on information being available from higher or lower functional levels, as well as other factors. The levels are listed below and shown in figure 1.

- Level 4: Business planning and logistics
- Level 3: Manufacturing operations management
- Level 2: Monitoring as well as supervisory and automated control of the production process:
  - Batch control
  - Continuous control
  - Discrete control
- Level 1: Control of process or machinery and data acquisition
- Level 0: Production process

2 MES AND NORMATIVE STANDARDS (VDI 5600 / IEC 62264)

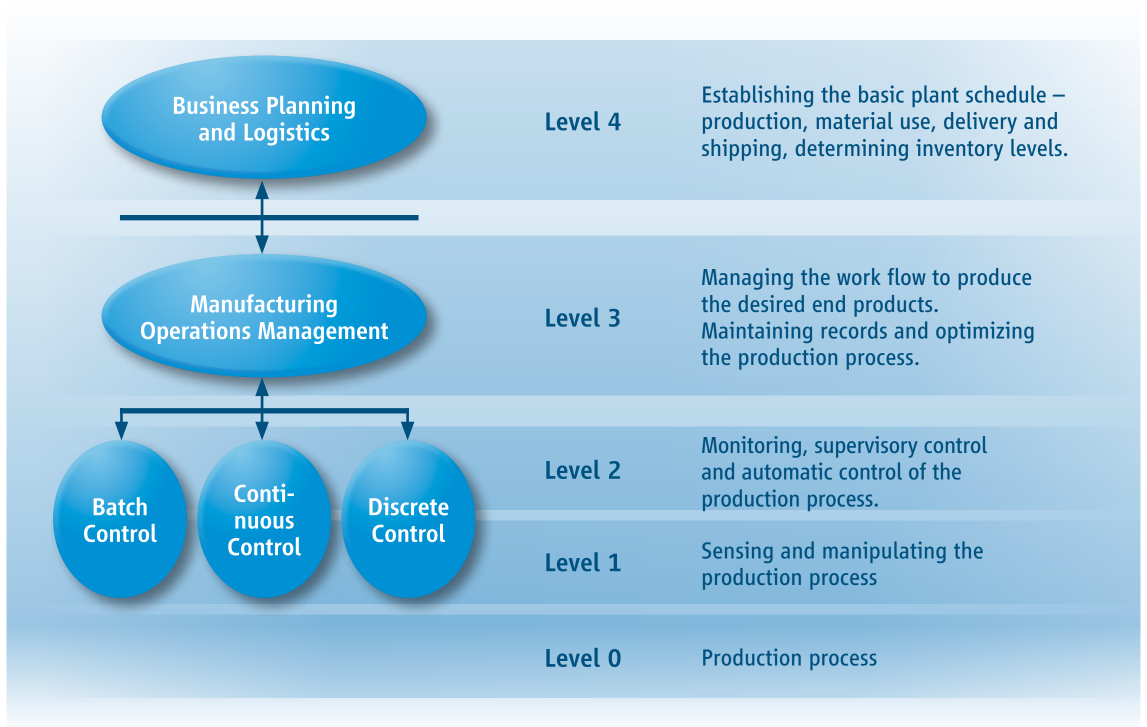


Figure 1: Functional hierarchy according to IEC 62264-3, Fig. 2 [4]

Part 1 of the standard describes the relevant functions in levels 3 and 4 for all divisions of an enterprise, and the objects which are normally exchanged between them. Figure 2 provides a general overview of the divisions and the relationships between them.

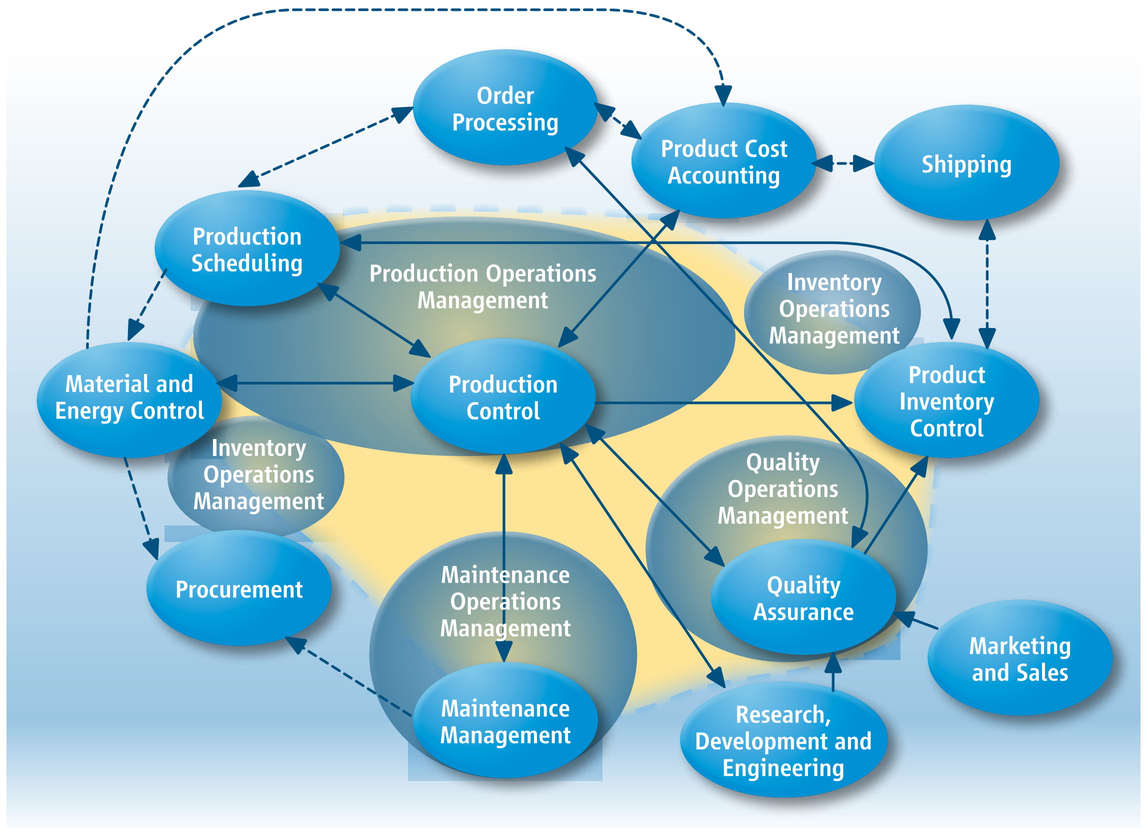


Figure 2: Manufacturing operations management model according to IEC 62264-3, Fig. 1 [4]. MES-relevant areas are highlighted in gray

The terms, concepts, and models defined in IEC 62264 provide a standard terminology for the integration of the corporate and production management levels. This improves communication between all stakeholders in MES projects. The standard also facilitates best integration practices for the integration between the corporate and production management. At the same time, the standard is independent of the degree of automation and the use of particular technologies.

In part 2 of IEC 62264 the characteristics and attributes of exchanged objects are defined. Part 3 describes the activities and functions related to the management of a manufacturing or process plant. This brochure is primarily concerned with the operational activities related to manufacturing, rather than the interfaces between the functional areas. Therefore, figure 2 presenting the areas of manufacturing operations management and the generic model of management activities shown in figure 3 are referenced in subsequent chapters.

The activities related to the functional enterprise control model shown in figure 2 can be assigned to the manufacturing operations management level (level 3 and shown in yellow) and divided into the following four functional areas (gray background):

- Production Operations Management
- Quality Operations Management
- Maintenance Operations Management
- Inventory Operations Management

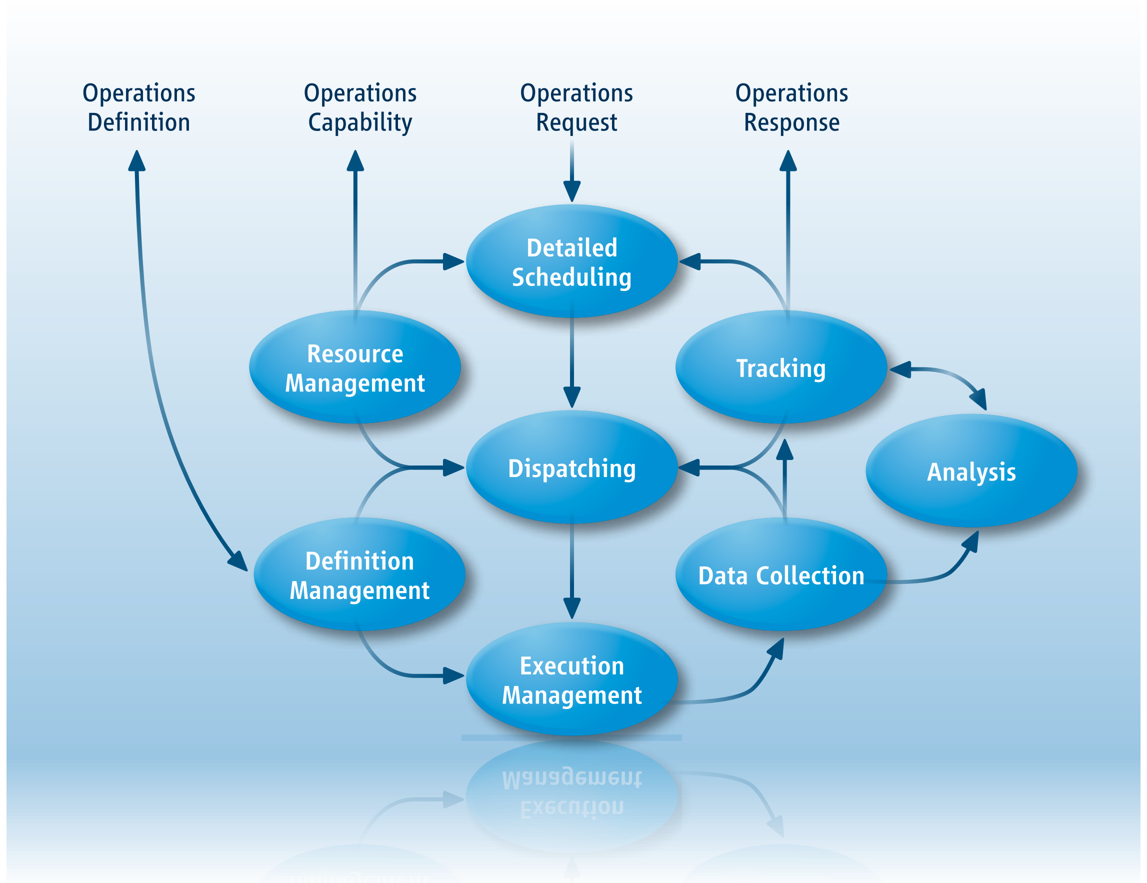


Figure 3: Generic activity model of manufacturing operations management according to IEC 62264-3 [4], Fig. 6

2 MES AND NORMATIVE STANDARDS (VDI 5600 / IEC 62264)

The activities modeled in Figure 3 primarily address the questions:

- How should …? (Specification management)
- What, where, and who can …? (Resource management)
- When, where, and who should …? (Detailed scheduling and dispatching)
- What is and needs to be done where and by whom …? (Execution management)
- When, where, and by whom was…? (Data acquisition and tracking)
- How was …? (Data acquisition and analysis)

These activities can be applied uniformly across all four functional areas of the manufacturing operations management level: production, quality, inventory, and maintenance. Since this model is particularly well suited for the structuring and description of MES modules, it is used as the basis for a more detailed explanation of the individual activities in the next chapter.

The analysis of existing or planned architectures may show that some of these activities are implemented in different systems, for example as functions in an MES module, in an ERP system, or in a process control system. Figure 4 provides an example about the technical integration of Manufacturing Operations Management activities and their assignment to different technical implementation layers.

While allowing a multitude of other activity-to-level assignments depending on specific requirements, the generic activity model can be used to describe the complete solution and defines the necessary interfaces.

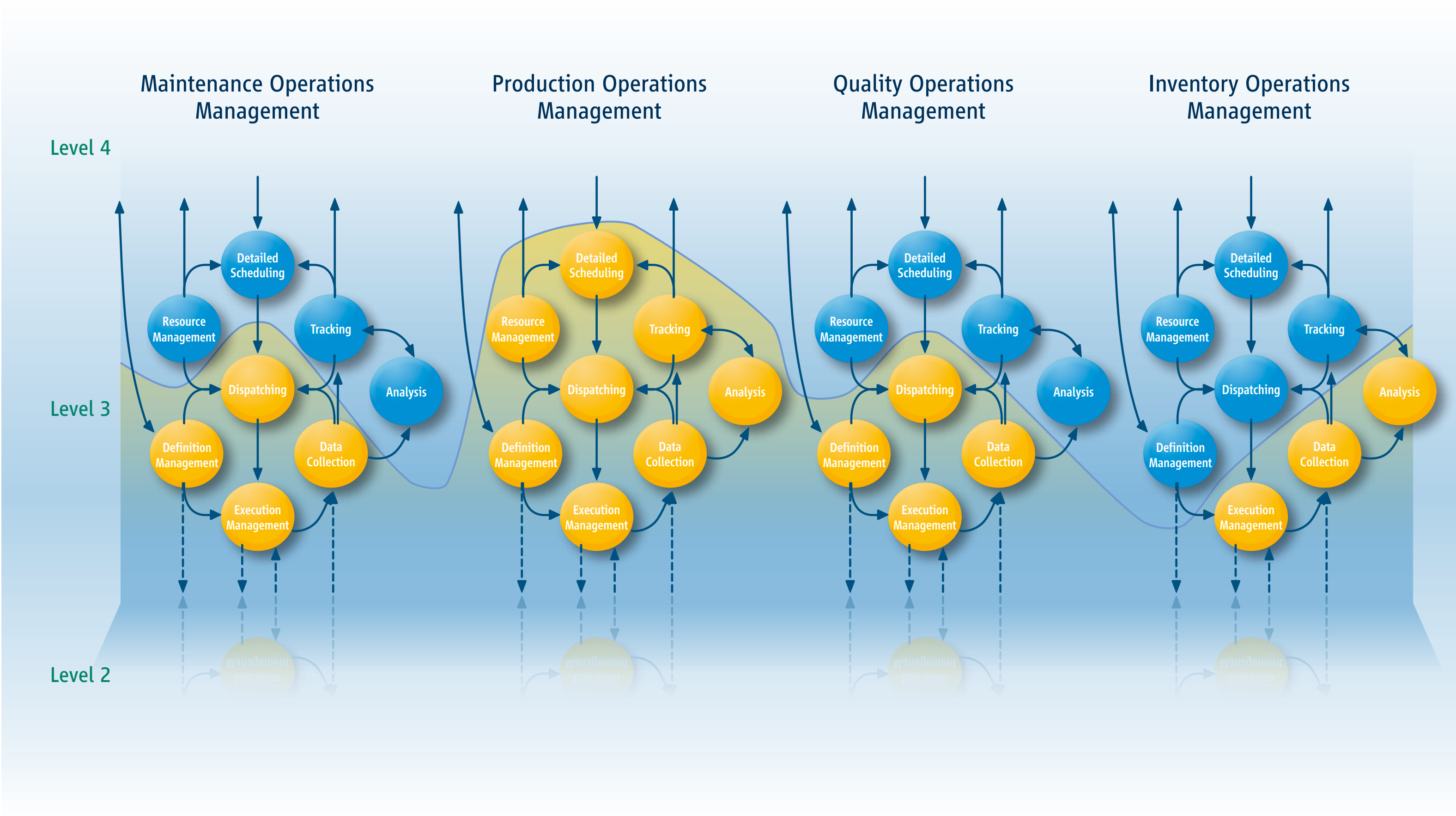


Figure 4: Different categories of activities and their technical integration (exemplary) according to IEC / EN 62264-3 [4], Fig. 31

3 Classification of the process model according to IEC 62264

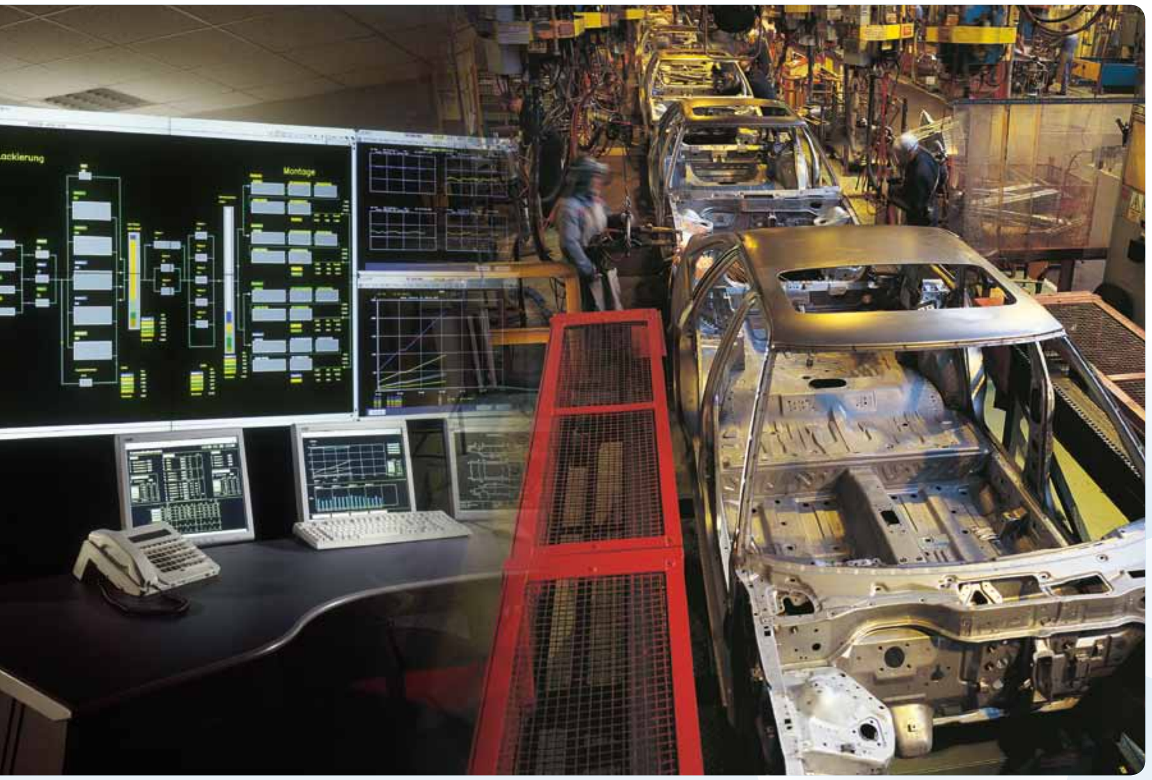
The Manufacturing Operations Management constitutes the functional core of MES as shown in figure 2, and itself consists of Production Operations Management, Maintenance Operations Management, Quality Operations Management, and Inventory Operations Management. They represent a bridge between functions typically considered as belonging to ERP, and the functions implemented in levels 1 and 2 of the functional hierarchy (see figure 1). All of these core functions consist of different individual elements, which provide or process information.

This operational information can be categorized as follows:

- Definition information – Specification of operations to be carried out and the required resources
- Capability information – Resource properties
- Schedule/request information – Scheduling and execution
- Performance/response information – Feedback of performance and results

The different areas of Manufacturing Operations Management follow a generalized activity model (Figure 5), which describes the interaction of the individual elements. The activities themselves consist of specific tasks, which differ according to the functions which need to be performed.

The individual activities are linked by information flows. The specific information exchanged between the activities depends on the respective functions. The activities and the information exchange are implemented by MES software products, which are function, industry, or product specific.



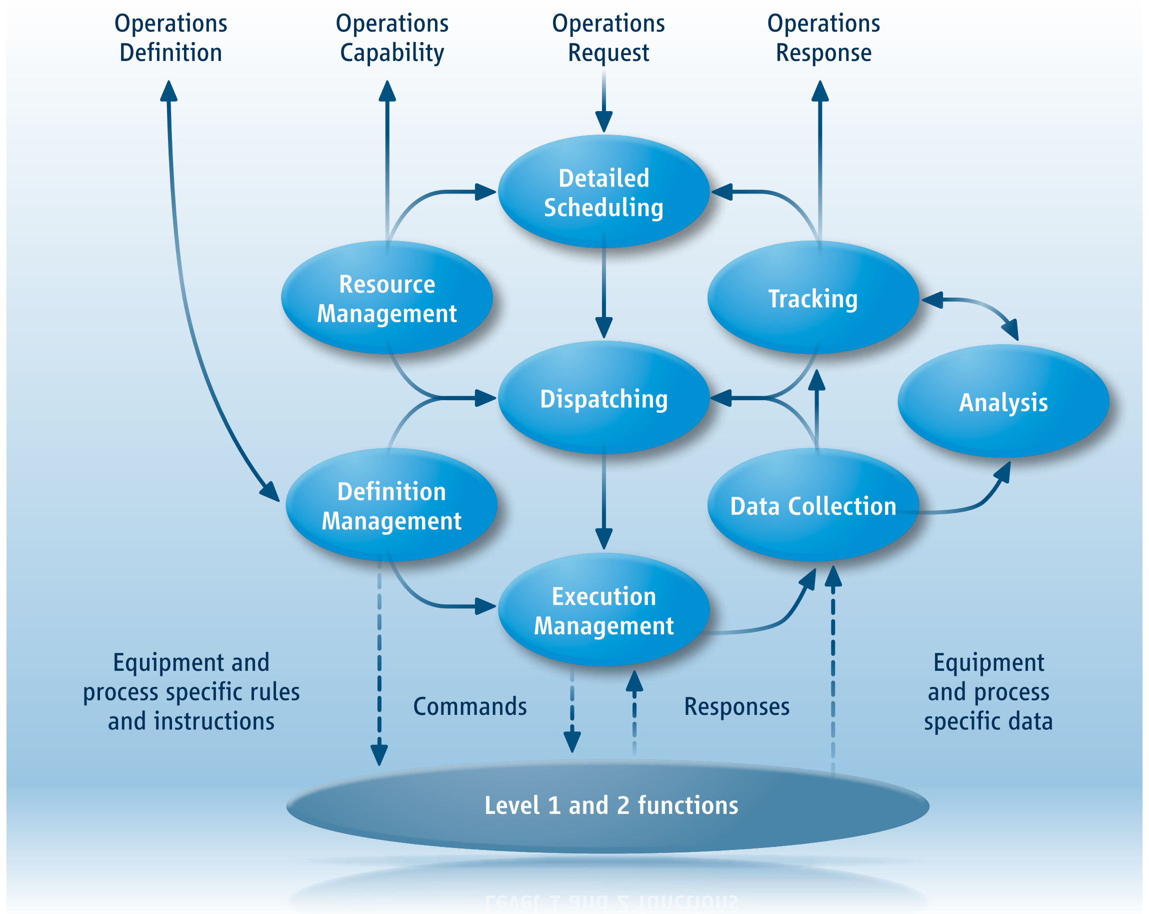
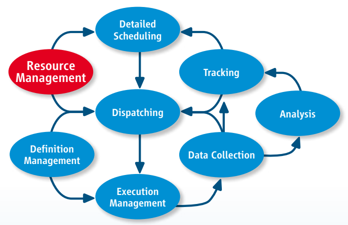


Figure 5: Generic activity model based on Figure 3 and extended by the process interfaces

3.1 Resource Management



Resource Management includes the administration of information related to possibly distributed resources, which are required for the respective functions of Manufacturing Operations Management. The information includes resource capacity and allocation as well as current and future availability.

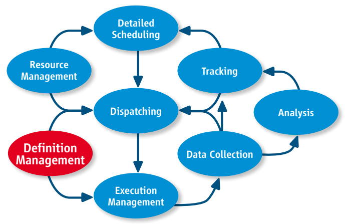
Thus, Production Resource Management focuses on resources which are needed for production, such as machinery, tools, staff and expertise, materials and energy as well as entire production steps.

Quality Test Resource Management specifies the staff requirements (including expertise, certificates, and authorizations), materials, and equipment necessary for performing quality tests.

Maintenance Resource Management covers information about the resources required for maintenance orders and work: standard and special tools, internal and external personnel (with appropriate expertise and qualifications), maintenance documentation as well as spare parts and consumables needed to perform maintenance work. The state of resources includes the equipment's health status, capabilities, availability, expected utilization, location, and location accessibility. Furthermore, it must be considered whether the maintenance work can be carried out during ongoing operations or whether equipment shutdown is unavoidable.

Inventory Resource Management is concerned with resources for material inventory and movement of materials, personnel (including expertise, certificates, and authorizations), consumables, and energy. Inventory levels and capacities are also taken into account.

3.2 Definition Management



Definition management comprises definition and administration of characteristics, processing instructions, regulations, and requirements for the different functions of Manufacturing Operations Management.

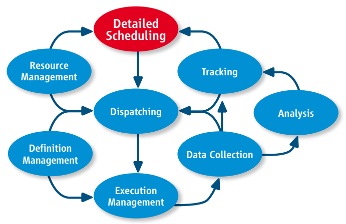
Production Definition Management includes the definition and administration of (possibly distributed) information about the products, their features, and their manufacturing process (manufacturing rules, recipes, Standard Operating Procedures (SOP), Standard Operating Conditions (SOC), transportation, and assembly sequences).

Quality Test Definition Management covers the definition and administration of personnel qualifications, procedures for quality testing, and work instructions for performing these procedures. This also includes test methodology, test frequency (sample plan), and tolerance information about material and resources. In addition, version and date administration of test specifications is included.

Information and instructions needed for performing maintenance work are defined and managed within Maintenance Definition Management.

Inventory Definition Management consists of activities for specifying and administering storage and transportation instructions for materials, including inventory levels, shipping instructions, and warehouse-related parameters such as utilization.

3.3 Detailed Scheduling



Detailed Scheduling incorporates the activities related to the creation of time-related demands and sequences for the optimized utilization of local resources for the respective functions of Manufacturing Operations Management. The activities are usually based on an existing plan.

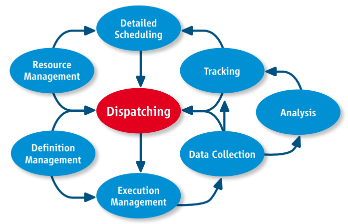
Detailed Production Scheduling addresses the organization of production equipment such as machinery and plants for which a detailed and optimized schedule is set up. The schedules include parameters such as batch sizes and set-up times as well as availability and utilization of resources. Resource availability may require defining several schedules.

Detailed Quality Test Scheduling focuses on the planning of quality tests which may be performed within or outside the production processes. Among other things, this covers the availability of test systems and personnel, and scheduling of test preparation and test evaluation.

Detailed Maintenance Scheduling comprises the examination and prioritization of maintenance requirements, and the time-related integration of maintenance activities into the production process. Production scheduling aspects such as product changes and planned shutdowns must be considered if applicable.

Detailed Inventory Scheduling manages collecting information about inventory levels and material movements. This also includes resource planning and optimization of transportation processes.

3.4 Dispatching



Dispatching incorporates activities for the administration and coordination of Manufacturing Operations Management. The basis for dispatching are, among other components, the schedules for individual resources created as part of Detailed Scheduling.

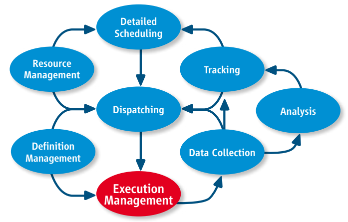
Production dispatching controls the flow of production by allocating equipment and personnel. For example, this includes the scheduling of batches in a batch control system and issuing work orders.

Quality Test Dispatching consists of issuing test orders to quality control facilities according to test plans. This may also include the submission of samples.

Maintenance Dispatching focuses on issuing maintenance orders to resources concerned with maintenance, while considering available internal and external personnel capacities.

Inventory Dispatching consists of the issuing of orders for examining stock levels according to definitions and schedules.

3.5 Execution Management



The purpose of Execution Management is management and optimization of the production process based on schedules, orders, and compliance with standards.

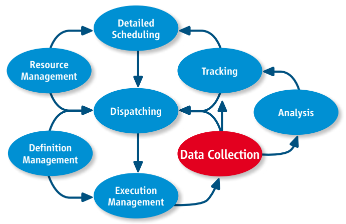
Production Execution Management refers to the actual production processes and executes activities such as selection and start of production steps according to product definitions and manufacturing instructions. It also manages the transfer from one production step to the next. At this point, information regarding the materials utilized and the processing time are collected. Thus, the status and current progress of the order become available. Based on this information, the production steps can be locally optimized.

Quality Test Execution Management concentrates on performing quality tests, and monitors the utilized resources (equipment, material, personnel) as well as compliance with quality standards, product characteristics, and tolerances.

Maintenance Execution Management controls and monitors the execution of maintenance orders. This includes checking compliance with service and repair instructions, regulations and quality standards, as well as proper documentation of status and results. Proper certificates for equipment, spare parts, tools, and personnel are monitored and used in dispatching. Unforeseen events are forwarded to Detailed Scheduling.

Inventory Execution Management comprises stock-related tasks. These include checking whether the correct storage, transportation, and personnel resources are being used. Compliance with quality standards and regulations for storage, transportation, and status reports, stock monitoring and accounting are also part of Inventory Execution Management.

3.6 Data Collection



Data Collection consists of the acquisition, (pre-) processing, and administration of data from specific processes within Manufacturing Operations Management. In most cases, this data originates from levels 1 and 2 of the functional hierarchy (Figure 1). The data may also be generated by user-initiated inputs and actions. They may be collected periodically or event-driven and represent the measurements directly (in engineering units) or indirectly (derived or integrated values). For correct evaluation of the data, typically the context in which the data has been collected is required, for example time stamps.

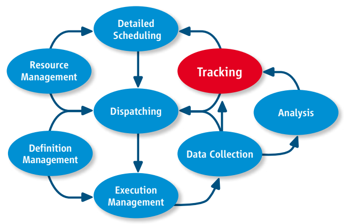
Production Data Collection is concerned with data related to the production operation or its individual steps. This includes sensor values and status information as well as results obtained by execution of production-relevant transactions and from the evaluation of models.

Quality Test Data Collection incorporates the actual test data, data about the test execution, user data entered during the test, intermediate data, and the data in the test reports.

Maintenance Data Collection focuses on data created during the execution of maintenance orders. This includes the current state of the operational equipment being serviced or repaired, the feedback on time and cost incurred by internal and external resources, as well as the comparison between the estimated and actual effort. The collected information will be integrated into the equipment-specific maintenance history record.

Inventory Data Collection concentrates on the acquisition and evaluation of data for stock-related activities and processed material. Product Tracking data such as stock level, storage status, utilized equipment and involved warehouse and transportation operators is also included. Inventory Data Acquisition is also used by other functional areas such as Quality Tracking (sample administration, administration of reference material) and for Maintenance Tracking (spare parts stock). This type of information may be required for regulatory compliance and must be integrated into the production data.

3.7 Tracking



Tracking consists of generation of feedback and responses from the specific processes of Manufacturing Operations Management to the associated functions of level 4.

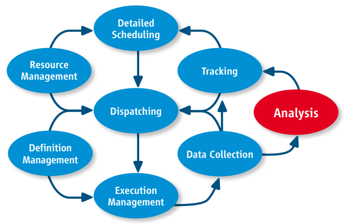
Production Tracking includes the summation and evaluation of information related to resources utilized for production such as personnel and production equipment, consumed and produced materials, and costs and results of performance analysis. Production Tracking also transfers information to Detailed Production Scheduling, so that schedules can be updated based on current conditions.

Quality Test Tracking provides feedback on quality to associated functions in levels 3 and 4. It compiles test results into test reports and manages information related to the utilization of test equipment. The test reports can be created on demand or time and event-driven, for example at the end of a production step or batch. Such test reports can be created at different times and for different units.

Maintenance Tracking focuses on information related to the utilization of resources during maintenance and the relative effectiveness of maintenance results, including the generation and updating of datasets about the state and usability of both serviced operational equipment and auxiliary equipment used during the execution of orders. This information may be required as proof of regulatory compliance.

Inventory Tracking comprises reporting of warehouse activities (for example, start and completion of transportation), stock utilization, lot sizes, and the current lot location. This includes generating and updating datasets related to the transportation and administration of the materials in stock. The collected information may also be used for quality test purposes and for proving regulatory compliance.

3.8 Analysis



Analysis includes activities related to the evaluation and reporting of (performance-related) data to business systems.

Production Performance Analysis concentrates on information about production (plant, unit) cycle times, utilization of production equipment, load and performance of facilities, effectiveness of procedures, and production variability. Based on these analyses, Key Performance Indicators (KPI) can be computed either time-driven, for example at the end of a production run or batch, or on demand. The KPIs are used to optimize production and consumption of resources. The process of Production Performance Analysis and Optimization is carried out in parallel with production. Changing optimization criteria and additional internal or external constraints, such as market and environmental conditions, may require repeated analysis, revision of policies, and re-optimization.

Quality Performance Analysis evaluates quality test results and test performance in order to improve product quality. This is typically a continuous process, and it includes the analysis of quality deviations, cycle times of quality tests, effectiveness of tests, and utilization of resources. In addition, it can entail determination of trends for (critical) quality indicators as well as root cause analysis for quality problems and recommendations for their correction.

Maintenance Analysis examines the expenses on personnel, spare parts, auxiliary equipment, direct and indirect costs as well as the organizational sequences in maintenance processes, in order to reveal problem areas and optimization potential for additional improvements. The emphasis is on optimization of maintenance strategy and maximization of Return on Assets (ROA). Results of the analysis can be used as feed back for production scheduling. The results can be used to compute Maintenance Performance Indicators, which help assessing the maintenance´s effectiveness. Furthermore, these results and findings provide decision support for improving efficiency of business processes.

Inventory Analysis includes information concerning the analysis of stock efficiency and resource utilization. This comprises material delivery including quality and on-time arrival, inventory losses, and material movements in relationship to storage location, equipment and shift. In addition, flow of materials, history of inventory resources, and trends are tracked and analyzed. From these, Inventory Indicators are derived which can be used internally in Manufacturing Operations Management for optimization purposes. In addition, the indicators can be forwarded to business processes at level 4. At this level, their combination with financial information provides the relevant cost-related indicators.

4 Typical MES modules and related terms

4.1 Overview

The industries addressed in this brochure use differing terms with regard to specific MES functions and their specific use. Sometimes the same terms are used by different industries for different purposes.

The following table is arranged into general, cross-industry, and industry-specific terms. The table provides an overview of the fields of application of the respective modules as well as their use. For each module, the specifically main supported areas and activities are listed. The table provides only a general overview without claiming completeness.

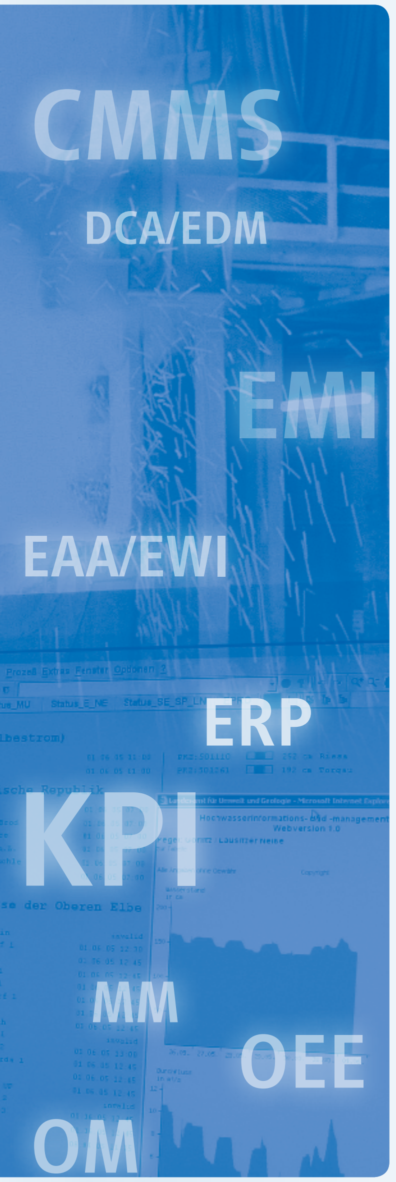
			Areas				Activities							
Acronym / Term	**Meaning / Task**	**Level**	**Production**	**Quality**	**Maintenance**	**Inventory**	**Resource Management**	**Definition Management**	**Detailed Scheduling**	**Dispatching**	**Execution Management**	**Data Collection**	**Tracking**	**Analysis**
	1. Industry in general													
CMMS	Computerised Maintenance Management System	3/4			✔		✔	✔	✔	✔	✔	✔	✔	✔
DCA	Document Control and Archiving	3	✔					✔						
EWI	Electronic Work Instruction	3	✔	✔	✔	✔		✔			✔			
EMI	Enterprise Manufacturing Intelligence	3	✔	✔	✔	✔								✔
ERP	Enterprise Resource Planning	4	✔	✔	✔	✔	✔							
KPI	Key Performance Indicator	3	✔	✔	✔	✔						✔		✔
MM	Material Management	3	✔	✔		✔	✔	✔				✔	✔	✔
OEE	Overall Equipment Effectiveness	3	✔	✔	✔							✔		✔
OM	Order Management	3	✔			✔	✔		✔	✔	✔		✔	
PAMS	Plant Asset Management System	3			✔		✔	✔			✔	✔	✔	✔
PRM	Personnel Resource Management	3	✔	✔	✔	✔	✔		✔	✔	✔		✔	✔
PLM	Product Lifecycle Management	4					✔	✔				✔		
PPS	Production Planning and Scheduling	3/4	✔		✔		✔		✔	✔	✔		✔	
QMS / QA	Quality Management System / Quality Assurance	3/4		✔			✔	✔			✔	✔	✔	✔
SCADA	Supervisory Control and Data Acquisition	2/3	✔								✔	✔	✔	
SCM	Supply Chain Management	3/4	✔		✔	✔	✔				✔	✔		
SPC	Statistical Process Control	3	✔								✔	✔		✔
SQC	Statistical Quality Control	3		✔				✔			✔	✔	✔	✔
T&T	Tracking and Tracing	3	✔	✔		✔	✔					✔	✔	✔
WMS	Warehouse Management System	3/4				✔	✔			✔	✔	✔	✔	

			Areas				Activities							
Acronym / Term	**Meaning / Task**	**Level**	**Production**	**Quality**	**Maintenance**	**Inventory**	**Resource Management**	**Definition Management**	**Detailed Scheduling**	**Dispatching**	**Execution Management**	**Data Collection**	**Tracking**	**Analysis**
	2. Manufacturing Industry (large series and single part production)													
CKM	Car Kit Management	3	✔			✔	✔			✔	✔	✔	✔	
Detailed Scheduling	Detailed Scheduling of manufacturing orders (mainly single part production)	3	✔				✔		✔	✔	✔			
GEN	Genealogy of final product parts	3		✔								✔	✔	
JIS / JIT	Supply of parts (JIS - Just in Sequence) / (JIT - Just in Time)	4	✔			✔	✔			✔	✔	✔	✔	
KBM	Kanban Management	3	✔			✔	✔			✔	✔	✔	✔	
MDA	Machine Data Acquisition (Parts, Process parameter)	3	✔	✔			✔					✔	✔	✔
PDA	Production Data Acquisition (normally manual data acquisition within production environment)	3	✔	✔	✔	✔						✔	✔	✔
PMC	Production Monitoring and Control; Acquisition, Processing and Monitoring of Event and Process Data --> see also SCADA	3	✔	✔			✔				✔	✔	✔	✔
RTLS	Real Time Locating System (Vehicle Tracing and Location)	3	✔			✔	✔					✔	✔	✔
RWM	Rework Management	3	✔	✔			✔				✔		✔	✔
Sequencing	Real Time Scheduler (RTS), realtime answer to sequence changes	3	✔				✔		✔	✔	✔			
	3. Process Industry													
AM	Alarm management	2/3	✔	✔			✔	✔			✔			✔
APC	Advanced Process Control	2/3	✔	✔			✔		✔		✔			
LIMS	Laboratory Information Management System	3		✔				✔	✔	✔	✔	✔	✔	✔
PIMS	Process Information Management System	3	✔	✔								✔	✔	✔
DCS, PAS	Distributed Control System, Process Automation System	2	✔								✔	✔	✔	✔
	3.1. Batch Processes													
Batch Analysis	Evaluation of Batch Records (e.g. Golden Batch)	3	✔	✔	✔		✔				✔		✔	✔
Batch Control	Recipe procedure coordination	2/3	✔			✔	✔		✔		✔	✔	✔	
EBR	Electronic Batch Record	3	✔	✔		✔						✔	✔	
Recipe Editor (incl. Recipe Authoring, RA)	Recipe definition	2/3	✔				✔	✔						
Scheduling Center	Monitoring and Control of Disposition	3	✔				✔		✔	✔	✔			
WD	Weighing and Dispense	3	✔					✔			✔	✔		
	3.2. Continuous Processes													
BMA	Blending and Movement Automation	2/3	✔	✔		✔	✔	✔	✔	✔	✔		✔	
BPC	Blend Property Control	2/3	✔	✔							✔		✔	
BRC	Blend Ratio Control	2	✔								✔			
LP Model	Linear Programming Model	3	✔	✔		✔	✔	✔						
RPMS	Refinery and Petrochem Modeling System	3	✔	✔		✔	✔	✔	✔					
	3.3. Filling and Packaging													
LMS	Line Monitoring System	2/3	✔				✔				✔	✔		✔

Table 1: Classification of typical MES modules and MES-related terms

4.2 Short description of typical MES modules and MES-related terms

4.2.1 Industry in general



CMMS – Computerized Maintenance Management System
A CMMS is used for administration, planning, control, and monitoring of maintenance-related data, capacities, and orders as well as associated cost and performance measures.

DCA – Document Control & Archiving
System or MES module for processing, administration, storage, and retrieval of relevant documents. Key functions include: electronic storage; access-rights management for documents; organization of document workflows depending on document type and status as well as predefined processing times; document archiving including version and history management.

EWI – Electronic Work Instruction
For each type of equipment, event or purpose, EWIs specify under which conditions and in which way the work shall be carried out and documented. EWI also defines the personnel and resources required for that work.

EMI – Enterprise Manufacturing Intelligence
EMI is a software system which integrates and correlates production-related data which are typically stored in multiple and distributed corporate systems.

ERP – Enterprise Resource Planning
An ERP system is a corporate IT system for integrated management of financial and production-related business processes. It is used for monitoring and controlling processes as diverse as strategic planning, production, distribution, order processing, and inventory management.

KPI – Key Performance Indicator
KPIs are performance and economic measures indicating the degree to which strategic and operational goals have been accomplished.

MM – Material Management
Material Management includes the planning and control of material flow during production as well as the associated flow of information. Generally, the material data is imported from the ERP / WMS system and used for administration and handling of inventory in manufacturing.

Important functional components manage identification, cataloguing, disposition, planning, procurement, quality control, packaging, storage requirements, etc.

OEE – Overall Equipment Effectiveness
OEE is a performance measure indicating the overall effective utilization of technical equipment. The OEE is expressed as a percentage and measures the actual equipment utilization against the theoretically possible maximum utilization.

Manufacturing OEE is calculated as the product of availability in hours, equipment performance, and produced volume meeting the quality specification. The reference value for OEE is the available maximum gross production time available to production scheduling.

Another factor used in business OEE is the planned non-utilization of equipment. This value is based on the total number of hours per year (8.760 h).

OM – Order Management
Order Management ensures timely and accurate procurement of resources in order to guarantee on-time production and delivery.

PAMS – Plant Asset Management System
A Plant Asset Management System is a software system for managing and online monitoring of production-related equipment. This specifically includes machinery, field devices, and associated hardware and software. Using real-time monitoring, PAMS also facilitate optimized inspection and maintenance of all assets based on their current condition. The basic concepts of Plant Asset Management apply to process as well as manufacturing industries.

PRM – Personnel Resource Management
A PRM system manages the available human resources and optimizes work assignments based on task requirements, time constraints, and skill sets.

PLM – Product Lifecycle Management
Product Lifecycle Management (PLM) collects product-relevant technical, commercial, and administrative data covering the entire lifecycle of the product, and makes the data available for different product phases.

PPS – Production Planning and Scheduling
Production Planning and Scheduling are computer-based systems for operational planning and controlling of production in manufacturing facilities.

QMS / QA – Quality Management System / Quality Assurance
The purpose of a QMS is the improvements in products and processes. A QMS defines procedures to achieve the specified product quality. Quality Assurance (QA) ensures compliance with the procedures defined by QMS. For specific areas, certain procedures and their enforcement may also be required by law.

SCADA – Supervisory Control and Data Acquisition
SCADA systems are software systems which monitor and control technical processes. They visualize process execution, record process data, and allow the operator to control the equipment and the process. The process interface requires appropriate control and communications infrastructure.

SCM – Supply Chain Management
Supply Chain Management controls and coordinates the logistical networks in terms of information and organization. The logistical networks cover the entire value chain from the supplier, to manufacturing and production, to the end customer.

The objective of Supply Chain Management is to increase the efficiency across the supply chain and to coordinate business processes between suppliers, manufacturers, customers and logistics service providers.

SPC – Statistical Process Control
The use of SPC allows management and optimization of processes based on statistical parameters.

SQC – Statistical Quality Control
SQC monitors compliance with quality standards based on the results of frequently taken samples. The statistical algorithms implemented in SQC dynamically determine the sampling quantity and frequency.

T&T – Tracking and Tracing
Tracking and Tracing is a general term for the identification and tracking of products, whether in production, quality assurance, or shipping logistics. In production, the focus is on determining the production status of a product, possibly including its physical location. For quality assurance, the emphasis is on compliance with production requirements, with particular regard to health and safety considerations. Tracking and Tracing is an essential prerequisite for tracking parts (recall actions) and batches (food, beverage, and pharmaceutical industries).

WMS – Warehouse Management System
A Warehouse Management System is an IT system which manages stored products in terms of their amount and their value. In order to control inventory and maximize results, it includes areas such as procurement, receiving, shipping, dispatching, invoicing, receivables, and cash flow management.

4.2.2 Manufacturing industry (large series and single part production)

CKM – Car Kit Management
The term CKM originates from the final assembly of automobiles and represents a picking strategy in which the necessary vehicle-specific assembly parts are put into a „basket" before assembly. This basket accompanies the vehicle through the final assembly and contains the specifically selected components which are required during the assembly phases.

Detailed Scheduling
Detailed Scheduling, often used in combination with machine control centers, is a tool for detailed planning and execution of manufacturing orders. Constraints such as technological sequences as well as optimized set-up times and production quantities are also incorporated. Detailed Scheduling optimizes machine utilization, provides computer-based rescheduling due in case of changes (priority or express orders), and clearly displays the process execution. Thus, it ensures on-time and optimized production runs. Detailed Scheduling tools are mainly used for single-part production, but also in serial production using non-interlinked equipment.

GEN – Genealogy
Product Genealogy ensures that all parts which have been assembled into an end product can be tracked based on their manufacturer, origin, or specific attributes. Genealogy is also referred to as Tracing.

JIS / JIT – Just in Sequence / Just in Time
JIT (Just in Time) refers to the delivery of assembly parts directly to the assembly line or location at a specific predetermined time. The supplier commits to deliver the goods within the specified time window. The practice of JIT avoids large inventory levels and stocking times, and thus optimizes logistics costs.

JIS (Just in Sequence) takes JIT a step further and specifies the supply of assembly parts to the assembly line or location in the correct sequence. For example, during the final assembly of automobiles, the exterior wing mirrors are delivered in color order, which is determined by the sequence of the differently painted vehicles on the assembly line.

KBM – Kanban Management
Kanban is a simple, very efficient system based on cards or labels (the name originates from „signboard" or „billboard") for scheduling production and logistics. The system was developed in the early 1950´s as part of the Toyota Production System.

Kanban is an approach whereby the „pull" for resupply is created by material consumption. As such, the production is controlled and the material is supplied solely on the basis of the material consumed in production. The cards are the basic element of this control system and transmit the necessary information. Kanban loops can significantly reduce material inventory for production while simultaneously increase delivery reliability.

Today the physical card transfer is steadily replaced by computer-based information transfer. This is generally referred to as eKanban.

MDA – Machine Data Acquisition
Machine Data Acquisition collects information related to parameters, production indicators, status and running time of machines. This information is used for planning and controlling production orders.

PDA – Production Data Acquisition
Production Data Acquisition (PDA) collects current data and status information (e.g. order status, production metrics such as quantities, volumes, weights, quality data etc.) of running processes.

PMC – Production Monitoring and Control
Production Monitoring and Control consists of dynamic real-time systems that collect and process the complete range of production-related data such as quantities, process parameters, and plant and machine status. In case of unacceptable deviations or discrepancies, corrective steps which may include PPS input, are automatically executed. Depending on the degree of automation, data can be directly transferred to subordinate systems or result in appropriate instructions to personnel (for example, set-point changes, rejections, shutdowns).

RTLS – Real Time Locating System
RTLS is a system that enables the real-time location of objects fitted with transponders (such as automobiles for example), via multiple proximity measurements or multiple triangulation. The advantage of RTLS is that the location of an automobile or other object can be determined at any time. This allows optimization of refinishing operations or logistical processes. Another application is the automatic and unambiguous assignment of a screw connection to an automobile by means of an automated identification of screwdriver and vehicle.

RWM – Rework Management
RWM is always part of Quality Management and includes the organization of finishing as part of the completion of individual products. The performance of RWM requires the planning of the end product, work areas, spare parts, employees, and quality tests.

Sequencing
Sequencing determines the location of production of the product (machine allocation), the order in which the products or batches are to be processed (sequence planning), and the time of production (time planning). In case of a malfunction, sequence planning can minimize the effects by changing the processing order.

4.2.3 Process industry in general

AM – Alarm Management
Alarm Management presents a wide variety of methods, functions, and tools for preventing abnormal plant conditions and for providing support to operators in their handling and control.

APC – Advanced Process Control
Advanced Process Control provides control structures for economic process management and specific process optimization of multi-variable or discrete correlations in plants or units by enhancing the basic controls of a typically hierarchical concept.

The functionality and tools range from simple enhancements such as feed-forward or cascaded control to dynamic de-coupling of interactions, to model-based multivariable controllers and optimization using process simulation.

Typical modules include MPC (Model-based Predictive Control), RTO (Real Time Optimization), NLC (Non-Linear Control), SPC (Statistical Process Control) and Soft-Sensors.

LIMS – Laboratory Information Management System
A Laboratory Information Management System (LIMS) supports planning, controlling, evaluating, and archiving laboratory orders. It typically supports functions such as the administration of master data, the registration of orders and samples, definition of the scope of testing, allocation of samples and tasks to work stations, collection of results, data evaluation, report creation, and the release of the data.

PIMS – Process Information Management System
A Process Information Management System (PIMS) is used for the collection, integration, processing, archiving, and report generation of both current and historical information about the production process. It enables the central consolidation of production data and traceability of production sequences, and provides information for calculating production indicators.

DCS / PAS – Distributed Control System / Process Automation System
A Distributed Control System controls continuous or batch processes. It consists mainly of controllers directly connected to the process for the execution of the actual control and monitoring functions as well as of operator and engineering stations.

4.2.4 Process industry: batch

Batch Analysis
This software is part of a MES or DCS for assessing and evaluating the progress of production as well as the yield and quality of a batch. Typical functions are: determination and display of parameters, quality-relevant deviations and comparison with other batches and the „Golden Batch".

Batch Control
Batch control software is part of a MES or DCS for automatic execution of recipes in the form of electronic work or control instructions for lower-level automation functions.

EBR – Electronic Batch Record
EBRs are electronic and automatically generated batch logs, which document the production of batches and the associated selected recipe data, actual process data, and events.

This software is part of MES, and allows the definition, creation, administration, and storage of EBRs.

Recipe Editor, RA – Recipe Authoring
A recipe editor software module is part of a MES or DCS for the creation and administration of recipes. Recipes are rules for manufacturing products according to a predefined procedure. The recipes contain a description of what is necessary for the execution of the process and in which sequence and under which process conditions the procedural steps are performed. Depending on the degree of plant automation, recipes consist of work instructions for operators (on paper or electronically), and/or control instructions for automatic execution by the recipe control, which usually utilizes the lower-level automation functions of a DCS.

Scheduling Center
The Scheduling Center is an MES module for detailed scheduling, implementation, and status display of production orders in the process industry. Scheduling Centers refine the longer-term scheduling requirements which, for example, originate in ERP systems, using information provided by Plant Data Acquisition. Scheduling Center software also detects and tracks the required materials and facilities (MT – Material Tracking and ET – Equipment Tracking). The Scheduling Center's graphical display often uses dynamically updated Gantt-Charts, which indicate the planned and actual allocation of equipment as a function of time.

Scheduling Centers can be implemented as a manual planning board, as a standalone software solution, or as an integrated module within comprehensive operations management software.

WD – Weighing & Dispense
WD describes the weighing, preparation, and dispensing of materials usually added manually according to the specifications of the recipe. The weighed and labeled materials are made available in mobile containers, drums, or bags at the point-of-use and must be added to the correct batches at the correct time. MES WD software manages and documents these critical sequences.

4 TYPICAL MES MODULES AND RELATED TERMS

4.2.5 Process industry: continuous and petrochemical processes

BMA – Blending & Movement Automation
BMA software plans and optimizes blending operations and necessary transfers in a refinery with the objective of increasing plant profitability in this area and preventing abnormal situations. The individual BMA tools plan and monitor objectives, consider stock limitations, provide scheduling plans and product specifications, perform simultaneous data analysis, and establish key performance indicators (KPIs).

BPC – Blend Property Control
BPC controls and optimizes inline-blending processes of refining components into specification-compliant sales products according to defined quality criteria while meeting blending requirements and the composition of blending components as well as available capacities and equipment.

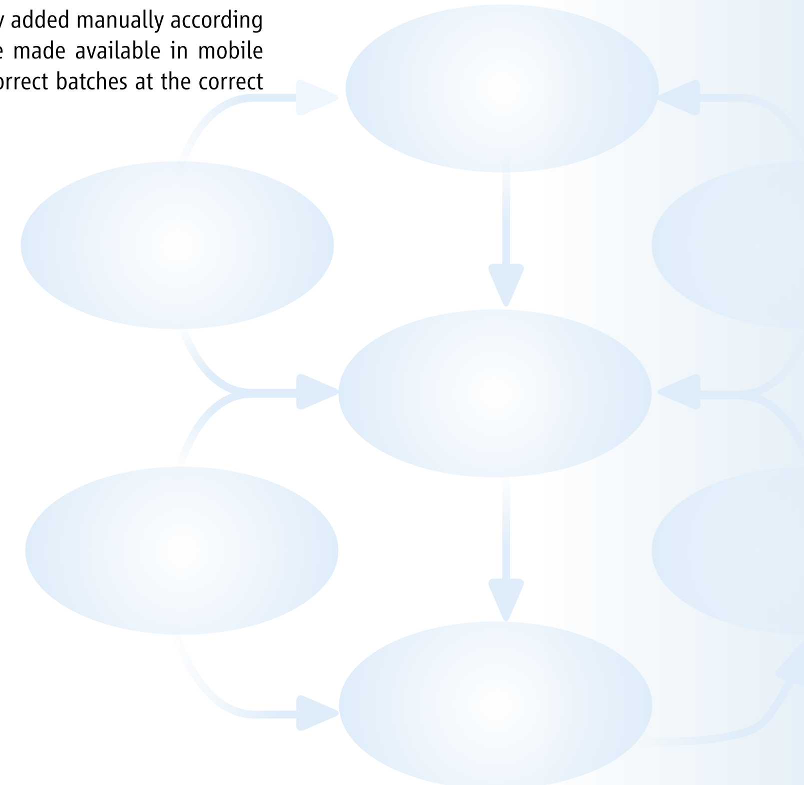
BRC – Blend Ratio Control
BRC directly controls the blending processes of refinery products according to manual or quality-driven settings.

LP Model – Linear Programming Model
An LP model consists of a modeled set of linear equations or inequalities describing the relationship of different variables with reference to an objective function, as well as a methodology for the solution of the system.

RPMS – Refinery & Petrochem Modeling System
RPMS are systems for the creation and analysis of LP models for short-term and long-term planning in refineries and petrochemical plants.

4.2.6 Filling and packaging

LMS – Line Monitoring System
Line Monitoring Systems are MES modules for collecting and monitoring production data in filling and packaging plants as well as related processes. Analysis and display of key performance indicators relating to the state of the line or plant are frequently part of an LMS. Typical indicators are throughput time, production quantities, utilization, breakdown times, failure causes, and packing losses.



5 Deployment, purpose, and environment of MES modules based on typical application examples

In the previous chapters, MES modules were industry-independently classified with regard to general process applications using the IEC 62264 standard and VDI guideline 5600. This chapter presents several industry-specific application examples with special consideration of the following two aspects.

1. Solutions which are today associated with Manufacturing Execution Systems have developed „organically" over a number of years in various applications. Over time, significant differences have emerged between the two principal industries „manufacturing industry" and „process industry". Yet even within each of the principal industries, special and application-specific variants have been established. These developments and the history they are based on will be outlined below.

2. In spite of the previously described differences, the industry-specific MES-related variations are presented using the structure of the IEC 62264 process model. As MES modules and solutions have continued to mature, techniques have emerged that are used across several application areas. This development is no exception in that in the last years, many process-related automation functions commonly used by both the manufacturing and the process industry have been implemented as hardware and software components (PLC, DCS). In addition, previously distinctly separate product lines are now used in both industries.

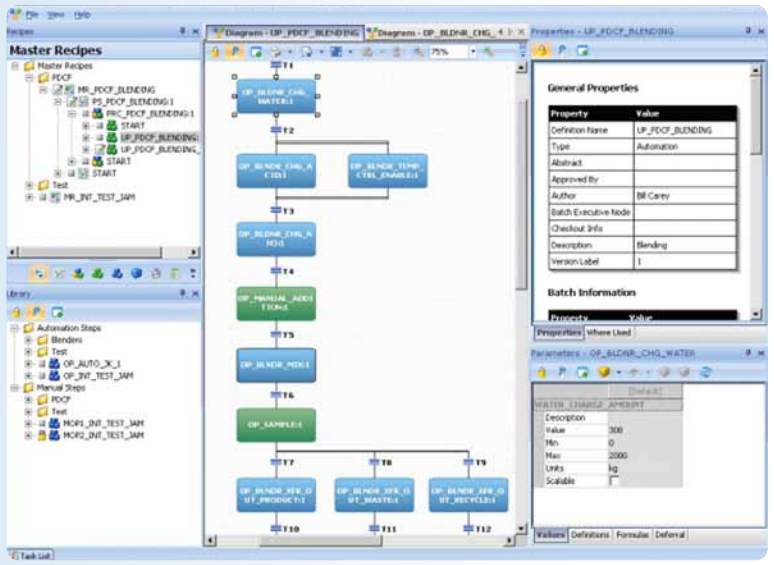
In order to guide the reader, the following chapters first provide a general description of the respective typical operational process, followed by a tabular overview of the individual operational activities in production, quality, maintenance, and inventory management which are supported by MES modules.

The following description of the general operational process provides a simple and straightforward overview of the main characteristics of each industry in order to correlate the functionality and application of the described MES modules.

5.1 Production of active pharmaceutical ingredients

In the pharmaceutical industry, active ingredients are produced by chemical or biotechnical processes (plant extracts, chemical synthesis, or biotechnological fermentation). The manufacturing process is subject to government regulations, which are generally summarized by the term „current Good Manufacturing Practices" (cGMP).

In the following example, the operational requirements and possibilities of applying MES modules are demonstrated for the chemical production of active ingredients in a flexible multi-product plant with automatic batch control. The emphasis is on production management.



5.1.1 General description of typical operations

Based on the demand for active ingredients, which is managed and forecast in the ERP system, their production is organized into campaigns.

Production recipes are available for each product, or must be created for newly introduced products. Depending on the degree to which the plant is automated, the production recipes are based either on instructions for the operators or on basic recipe phases (according to NAMUR NE33 or ISA S88), which are physically implemented in the process automation system (Figure 6). In addition to ingredient quantities and process control parameters, the recipes include requirements for plant interconnection, work instructions for manually performed steps (SOPs: Standard Operating Procedures), safety instructions for handling hazardous

Figure 6: Integrated recipe definition and management for MES (green) and DCS (blue) in a recipe editor within MES

materials, and quality control requirements including sampling (IPC: In Process Control, PM: Process Monitoring). As part of compliance with cGMP, the recipes are subject to version control, and require approvals from production management and quality assurance.

Production scheduling requires:

a) The selection and allocation of required process equipment (dosage vessels, reactors, filling stations, etc.), planning and allocation of any necessary flexible plant interconnections, and availability of mobile equipment.
b) Checking availability of qualified personnel who have received training regarding SOPs and handling of hazardous materials necessary for the product.
c) Checking availability of ingredients needed at the appropriate time.
d) The division of the campaign into individual production batches.
e) Generating of weighing and transportation orders for individual ingredient containers (big-bags, drums) that will be manually added to the process.
f) Generation of laboratory test orders for IPC and PM samples.

Production preparation requires:

a) Checking whether the planned equipment is cleaned and available or whether the status „cleaned" has expired by exceeding its time limit requiring new cleaning before usage. Documentation of equipment status.
b) Setting up flexible plant interconnections and allocation of mobile equipment. Checking and documentation of the interconnections for quality assurance purposes.

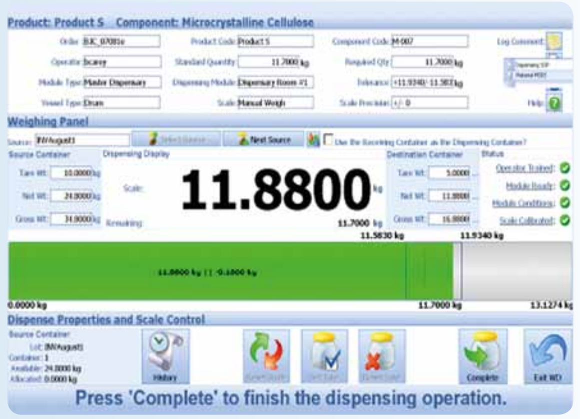


Figure 7: Operator guidance during recipe-based material weighing using mobile or fixed operator terminals

Production execution requires:

a) Producing the individual batches according to their production recipe either through manual operation according to the instructions contained in the recipes, or automatic recipe execution using the DCS. In both cases, cGMP-compliant documentation including „who did what and when" is required.
b) cGMP-compliant documentation of quality-relevant process parameters as proof of production of the batch in compliance with the parameters specified in the drug approval of the active ingredient.
c) cGMP-compliant weighing (Figure 7), documentation, labeling, and transportation of ingredient containers at the correct time and location in the plant.
d) Discharge of the correct container to the planned production batch at the correct time within the process. The discharge must be cGMP-compliant, i.e. either via operator confirmation and supervisor verification or automated verification e.g. via barcode.
e) Taking of samples and carrying out test orders.

Production evaluation requires:

a) Contemporaneous recognition of quality-relevant batch deviations in order to allow fast batch release by QA.
b) Additional operational evaluations, for example to minimize the variation of batch cycle time and yield.

Economic background:

Generally speaking, active pharmaceutical ingredients are high-value products. The cost of losing a single batch can exceed six figure sums.

5.1.2 Operations supported by MES functions

		Areas			
		Production	**Quality**	**Maintenance**	**Inventory**
Activities	Resource Management	**Employees** • Planning training requirements: which employee has been trained on what? How long is the training valid? When must it be repeated? • Link to Definition Management: what Standard Operation Procedures (SOPs) exist and which employees need training on them? • When is which employee available (planning of shifts and holidays)? • Link to Detailed Scheduling and Execution Management: do employees who should perform a cGMP-relevant task have the appropriate permission and training? **Process equipment** • Unit classes and their general attributes (type: reactor, receiver, centrifuge …; equipment states: cleaned, used, being serviced …) • Units and their individual attributes (equipment limits: volumes, temperature, pressure …; material: steel, glass, teflon …; special equipment: with/without dosing tank …) • general process resources like heating or cooling medium, nitrogen, vacuum, exhaust air scrubber etc. and their capacities • fixed and flexible plant interconnections and mobile equipment	**Employee** • Personnel training and qualification • Personnel availability **Test equipment** • Test equipment availability, calibration cycles, maintenance plans **Testing aids** • Stock and expiry dates of required testing aids	**Employee** • Personnel training and qualification • Personnel availability **Production equipment and instrumentation** • Types, quantity and status **Tools and calibration equipment** • Types, quantity and status **Spare parts and operating materials** • Required types and their stock levels **Maintenance contracts** • Outsourcing of maintenance activities	**Employee** • Personnel training and qualification • Personnel availability **Materials** • Material, quantity, status **Stores** • Stores, their type, capacity and allocation **Operational equipment and packing material** • Scales • Bins and packaging (containers, barrels, big bags …) • Transportation resources
	Definition Management	**cGMP compliant document creation, release and control** • Production and cleaning recipes (definition of automatic recipe for the PAS or reference to recipes stored in PAS and definition of Electronic Work instructions with link to SOPs for manual tasks) • Work instructions (SOPs) • Safety instructions	**cGMP compliant creation, release and control of** • Test methods • Test procedures and permitted tolerances • Test plans	**Creation, quantification, release and control of** • Maintenance plans • Test procedures • Calibration cycles	**Creation, release and control** • Materials, states, storage and transport conditions, minimum levels • Instructions for handling dangerous materials • Work instructions • Specification of permitted packaging
	Detailed Scheduling	**Defining and planning production campaigns** • Interface to ERP system for the transfer of process orders from the ERP system • Unit assignment proposal and selection based on recipe requirements and availability at the expected time • Connection setup proposal and selection corresponding to unit assignment and availability of connections at the expected time • Advice about resource and material bottlenecks at the expected time • Target vs. actual production comparison	**Planning** • Required tests for goods receipt , in-process control and product releases • Comparison of target vs. actual	**Planning** • Status dependent inspection and maintenance measures • Comparison target vs. actual	**Planning** • The material stock level necessary for production • Weighing the necessary containers while considering the materials' storage time (FIFO) • Required transport operations • Comparison target vs. actual
	Dispatching	**Order assignment for running production campaigns** • Order assignment for campaign set-up • Order assignment for weighing of ingredient containers (interface to Detailed Scheduling of inventory stock) • Order assignments for processing the individual batches in the campaign (interface to PAS) • Order assignment of test orders for the laboratory (interface to Detailed Scheduling of LIMS) • Order assignments for intermediate cleaning (may be automated via PAS) • Order assignment for final cleanup (may be automated via PAS) and dismantling of flexible connections at campaign end and shutdown	**Order assignment** • Test orders	**Order assignment** • Maintenance orders	**Order assignment** • Required sampling of received goods • Weighing of required containers • Required transport operations
	Execution Management	**Operation and monitoring of production campaigns** • Status display and operation of campaigns, their batches, material containers and transport orders **Carrying out electronic work instructions** • Displaying the electronic work instructions defined in the recipe in the context of batch progress • Checking if the employee has the appropriate permissions • In the case of manual material additions: checking container lot data (e.g. via barcode) and indication if the lot may be used	**Test execution** • Online access to test orders and test procedures • Automatic or manual execution • Documentation of results • Feedback to production and stores	**Control and monitoring of maintenance orders** • Online access to work orders, service plans, documentation and directives • Status tracking • Documentation of results	**Carrying out or helping operators with** • Material weighing • Transport • Release or quarantine of materials and products
	Data Collection	**Electronic data recording** • Recording and storage of data according to US legal requirements: 21 Code of Federal Regulations (21 CFR Part 11): Electronic Records; Electronic Signatures • Recording all MES events and operator actions associated with the course of a batch or campaign • Transfer of PAS batch events (operator actions, alarms, report values) to the batch data in MES or access to the data via data connector during the generation of an Electronic Batch Record, respectively • Transfer of LIMS analysis data to the batch data in MES or access to the data via data connector during the generation of an Electronic Batch Record, respectively	**Electronic data recording** • Test order and analysis results • Responsible employee	**Electronic data recording** • Failure time • Damage • Necessary working times • Spare parts needed • Maintenance order costs • Resulting costs of production losses	**Electronic data recording** • Material data (batch no., quantity, analysis values, quarantine status) • Stock levels and location • Use and status of mobile containers • Execution of transport orders
	Tracking	**Automatic tracking of** • State changes of campaigns, batches, work and transport orders and display in appropriate overview • Feedback of material consumption and manufactured products to ERP system	**Automatic tracking of** • Completed test orders • Warning if analysis values outside tolerance	**Collection of completed maintenance orders** • Qualified feedback, order status • Assignment of damage cause • Advice for future improvements and solving weaknesses	**Collection of completed** • Goods received • Shipped goods • Weighing • Transport orders
	Analysis	**Generation of electronic batch records** • Batch time progress • Quality-relevant discrepancies • Historic trend plots of quality-relevant measurements **Historic trend plot comparison of batches** • with a „Golden Batch" • Statistical analyses (variance of batch running time, yield etc.) **Material tracking and material genealogy** • Overview: which ingredients were used in a batch? • Overview: in which batches was a particular ingredient used? **Statistical analyses** • KPIs (yield, completion times, scrap, refinishing, level of utilization, resource consumption, costs)	**Statistical analyses** • KPIs (level of utilization, run times, resource consumption, costs) • Variance of quality data • Optimization of test plans	**Statistical analyses** • KPIs (level of utilization, repair times, resource consumption, costs) • Technical plant availability • Reliability of parts • Optimization of maintenance plans and intervals	**Statistical analyses** • KPIs (tied capital, turnover times, time spent in quarantine, costs) • Optimization of minimum stock levels and packaging units • Supplier evaluations

Table 2: MES modules for production of active pharmaceutical ingredients according to the process model

5.2 Food and beverages - brewing industry

The brewing industry is characterized by its large range of plant capacities. They vary from micro-breweries producing around 2.000 hl per year (400.000 bottles at 0.5 l) to the largest breweries in Germany with annual production of about 5 million hl, to breweries across the world with up to 10 million hl/a. Some breweries exceed even that number. The automation and MES requirements vary accordingly. In small breweries, generally only the brew-house and possibly some cleaning equipment operate automatically as „islands of automation". Starting at about 100.000 hl/a, breweries run the entire production process with a fully integrated automation solution. Large breweries operate as fully automatic production plants monitored from a central control room.

The main functions of MES are quality assurance, support of production scheduling including data for material flow and inventory, and evaluation of production with special focus on product quality and efficiency.

MES is regarded as the core function for goal-oriented support of production. Proprietary systems exceeding the scope of office software products are typically found in breweries producing about 500.000 hl/a. Because of the continuing concentration within the brewing industry into large, internationally operating concerns, the comparison of sites using selected performance indicators has also become increasingly important. MES provides these performance indicators.

The internal organization of production within a facility covers two main areas, namely brewing and bottling, i.e. the production of ready-for-sale beer from the raw materials and packaging into various containers. Both areas require different organization and MES functions. The following overview focuses on the production process, i.e. the brewing.

5.2.1 General description of typical operations

The preparation of beer falls into the four process cells:

- Silo area = raw material storage
- Brew house = preparation of wort
- Fermenting cellar = fermentation
- Filtration/ready-for-sale beer = beer filtration and preparation for bottling

For the most part, the raw materials used are malt and hops. Yeast is generated and reproduced within the production process. Consumable materials are cleaning agents and filtration aids. By-products include brewer's grain, yeast, and filtering aids.

Due to the complete brewing process requiring about 4 weeks, sales must be forecast accordingly in order to allow the necessary production lead time.

Quality variations in the raw materials and the market requirements with regard to product innovations require flexible recipe management. This functionality is usually implemented on the control system level. Recipes are defined at unit or plant level. Site or general recipes are less common and exist occasionally as manufacturing instructions. Recipe execution within the control system has been commonly used in breweries since the 1980s.

Production is scheduled separately in the individual process cells:
Silo area
a) Planning of raw material procurement from the ERP system
b) Posting within ERP, or in the case of integrated environments, via MES and feedback to ERP
c) Stock level and consumption feedback from MES to ERP

Brew house
a) Planning time frame: 1 week
b) Comparatively few varieties (approximately 1 - 10)
c) Planning brews by brewing line (Figure 8)
d) Tank volumes in the fermentation cellar (next stage) determine the number of identical brews in sequence
e) Input parameters for planning (Figure 9):
- Current levels in the fermentation cellar; empty capacity in the fermentation cellar is refilled.
- Long-term sales forecast for selecting brew variety. This determines the quantity of a brew type to be produced. The total quantity is divided into individual batches (brews) as part of planning.
- Planning uncertainties are caused by the 2 to 4 week delay between production in the brew-house and sale of the finished beer.

Figure 8: Tank scheduling used for scheduling support

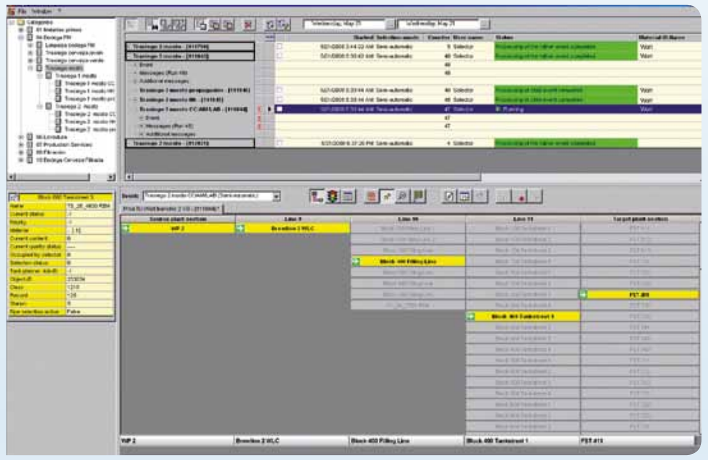


Figure 9: Automatic association of resources and process execution in MES

Fermentation cellar
a) Filling of tanks is determined by brew planning.
b) Long batch times of 1 to 4 weeks.
c) Emptying of tanks is determined by filtration planning.
d) The remaining work in the fermentation cellar (yeast culture, cleaning) is carried out as part of simple weekly scheduling.

Filtration and delivery of finished beer to bottling
a) Planning time frame is about 2 to 3 days.
b) Comparatively high number of varieties (approx. 5 - 50).
c) Quick adaption to planning changes in bottling.
d) Typical buffer time of less than 1 day to bottling.
Production scheduling is determined primarily by the availability of the plant and equipment, rather than scheduling of raw materials.

Personnel planning
The work is not subject to variations in required qualifications. Therefore, personnel planning must only schedule sufficient personnel for each shift. This is accomplished with simple lists.

Production preparation requires:
a) Supply of raw materials is the responsibility of the ERP system.
b) Selection and allocation of the required plant units and routes.
c) Checking the necessary status of the batches (quality release) as well as the plant (cleaning).
d) Request of the next processing steps under consideration of the current process status which is obtained from the process control system or MES.

Production execution requires:
a) Monitoring of automated processes.
b) Furnishing work flow descriptions for manual tasks.
c) Acquisition of production and consumption quantity data in MES.
d) Triggering required sample collection and performance of quality assurance analyses.
e) Blocking/releasing batches for further processing depending on quality results.
f) Requesting cleaning at the end of production.

Production evaluation requires:
a) Acquisition of batch data from the process control system.
b) Merging all relevant data (DCS, laboratory information management system, manual collection).
c) Checking selected data points against specification.
d) Quick overview of batches which have exhibited deviations from target values. This supports the identification of production problems.
e) Evaluation of the percentage of batches produced without defects.
f) Targeted evaluation of production based on a limited number of performance indicators.
g) Administrative evaluation of the produced batches by validation of the collected data.
h) Possibility to correct all collected data, including automatically collected data. Faulty data renders long term statistics useless and causes problems when exporting data to an ERP system.

5.2.2 Operations supported by MES functions

		Areas				
		Production		**Quality**	**Maintenance**	**Inventory**
Activities	Resource Management	**General** • Assignment of units and sub-units to possible processes occurs at control system level. This is specified according to the units' equipment in unit classes • Inflexible, technologically fixed process operation **Plants** • Resource management in DCS • Fixed specification of possible processes on the units • Frequently different lines with the same functionality (e.g. 2 brewing lines, multiple tank filling and emptying routes) • Production status management takes place in DCS • As well as the hygiene status (used, cleaned, sterilized) a process status is maintained: e.g.: filling, filled, emptying, empty, cleaning, etc.; alongside the procedural status according to S88.01 **Material** • Transfer of material classes and materials from ERP • Assignment of material classes to procedures in DCS • Assignment of materials to recipes in DCS **Employees** • In the case of total automation personnel can be assigned to all production areas • Personnel planning is rarely done in MES		**Requirements of product attributes** • Collection of required quality data **Collection and evaluation of ingredient attributes** • Analysis and storage of relevant ingredient attributes • Evaluate (accept or reject) • Evaluation of influence on production requirements, adjustment of parameters may be necessary **Administration** • Test equipment and testing means • Performance of analyses by laboratory or production personnel	**Strategic decision: situational or preventive maintenance** • Planning for equipment stand-still and repair (cyclical) • Envisage situational maintenance • Plan personnel to coincide with expected operational phases and short-term needs	**Planning of requirements and capacity for material** **ERP** • Long-term supply contracts for key components (malt / hops) • Reconciliation with data from previous year **MES** • Determine and manage current and historical stock levels (MES often leading ERP) • Feedback of consumption and production to ERP • Assignment to process order (dependent on connection to ERP) • Reconcile current levels, inventories
	Definition Management	**Definition of manufacturing procedures / recipes** • Definition of parameters in procedures and recipes takes place in DCS • Distinction: plant parameters, process parameters, product parameters • It is usual to define the procedures at unit class level, and the recipes at concrete unit level. Exceptions are tank farms, for which recipes only exist at class level • Link to SOP's for manual tasks **Specifications** • Entry limits for parameters are stored in the DCS • For quality-relevant parameters definition of limits takes place in MES => selection necessary • Checking against specifications only makes sense if quality defects are expected • Batch classification „not in specification" • Risk of bad evaluations when specifications are not maintained **LIMS interface** • Majority of specifications exist in Laboratory Information System • Feedback of limit violations from laboratory to the DCS • Reporting of quality-relevant in-situ measurements to the laboratory		**Specification of material characteristics** • Quality of ingredients • Ingredient tests and release procedure • Product qualities • Product test and release procedure **Quality data adjustment** • Mechanisms for order-related adjustment **Creation, release and control** • Test methods • Test procedures • Establishing limits • Ingredient release / restriction • Batch release / restriction for refinishing **Interface to DCS** • Quality release via online interface • Feedback to batch level	**Requirements for cycles and criteria for operational maintenance** • Procedure for maintenance orders • Maintenance lists (equipment, personnel) • Determine service intervals • Limits for maintenance requirement **Creation, quantification, release and control** • Calibration cycles for measurements • Object-oriented maintenance plans depending on operating hours, cycles) for selected components • Full maintenance in plant areas (service with scheduled shutdown)	**Fix provisions for stock levels (backup quantities)** • Minimum stock levels • Days of inventory definition
	Detailed Scheduling	**Scheduling of plant equipment and production assignments** • Transfer of production requirements from ERP or Supply Chain Management software • Brew-house: Splitting production requirements from ERP (quantity per product) into production batches (brews) in DCS • Fermentation: Necessary processes result from product status or cleaning requirements respectively; no higher-level planning • Filtration: Supply of filtered beer for bottling according to current stock levels and bottling planning from ERP • Assignment of operational production units (production lines / routes, units, vessels) in DCS • Short-term planning changes as required • Display of plant allocation and production status also in MES		**Logistical planning adjustments according to quality criteria** • Scheduling analyses in course of production • Creation of sampling plans from current batch information	**Handover of planning data** • To Maintenance Management modules	**Ingredients** • Call-up of deliveries depending on stock levels and production planning **Product** • Optimum from quantities required for bottling planning and shortest possible idle times
	Dispatching	**Optimum allocation of plant equipment according to scheduled and current operations data** • Functionality exists entirely in DCS • Start of production released manually or according to plant availability • Automatic selection of available units possible (request for e.g. cleaning from process) • Decoupling of operator activities in different process stages via MES modules • Production in fixed lot sizes, predefined within narrow limits by plant dimensions **Order assignment for running production campaigns** • Order assignments for intermediate cleaning which may be needed (possibly automated via DCS) • Feedback of process status as basis for planning		**Order assignment** • Taking of samples • Allocation of analysis devices	**Planning and adjusting resources in line with current requirements** • Demand for personnel	
	Execution Management	**Optimum management and control of production units** • Credo: production must also be possible without MES • Automatic or semi-automatic operational procedures with recipe control • Administration of variable parameter sets for discrete and regulatory control of plants (recipe contents) in DCS • Automated routing controls • Flexible choice of batch mixing, dosing, selection and de-selection of e.g. units like separators • Possibility of smooth switchover for tank changes, although the number of required tanks is not fixed at batch start time **Process control** • Monitoring process status in MES • List of current specification violations • Evaluation of production in MES (KPIs)		**Product quality** • Online measuring product quality during running production **Carrying out analyses** • Online access to test orders and procedures • Feedback of analysis results • Documentation of the results **Reactions** • Instruction to block or release ingredients and/or production batches • Transfer to DCS	**Control and monitoring of maintenance orders** • Collection of operating cycles, hours • Calibration intervals of field devices • Online access to work orders, service plans, documentation and procedures	**Stores** • Automatic posting on delivery • Assignment of delivery note data • Collection of manual stock movements (e.g. container goods); entry in stock and allocation to production **Levels** • Booking out used materials, posting of produced quantities • Booking correction on empty status • Manual inventory for current levels • Feedback to ERP

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		Areas				
		Production		**Quality**	**Maintenance**	**Inventory**
Activities	Data Collection	**Collection and display of current process data (control system)** • Reporting of all batches to MES, mostly to operation level (start and end times, total process run time, material identification, recipe version used etc.) • Classification of orders according to process or CIP respectively, as basis for reports • Use of current and recent (days, weeks) operating parameters which have been archived in components of the control system by operators in the control room **Long term archiving** • Collection and archiving of plant-wide operating data for current or future analysis; typically used outside the control room **Electronic data recording** • Recording of all events and operator actions associated with the progress of a batch or campaign • Transfer of batch events (operator actions, alarms, report values) from the DCS to batch data in the MES • Transfer of analysis data from the LIMS to batch data in the MES		**Definition, collection and filing of general quality indicators for the production operation** • Laboratory data collection: collection and storage of analysis data from process and laboratory **Electronic data recording** • Test order and analysis result • Responsible employee	**Updating maintenance data in case of plant changes** • Documentation of maintenance work • Collection of operating cycles • Collection of operating hours • Resetting meter values after maintenance work	**Consumption / Production** • Material movements (batch ID, storage location, material, quantity, etc.) • Building batch hierarchy (link between source and target batch) • Assignment of consumption / production to process batches • Material reservation method
	Tracking	**Tracking of production objectives** • Creation of condensed production overviews • Production parameters, losses, consumption • Ascertaining KPIs • Tracking allocation times **Reporting** • Predefined „Standard Reports covering recurring reporting tasks • User-configurable report queries allowing enhanced selection criteria and combination capabilities • Data transfer to and further processing within MS Excel **Production evaluation** • Number of batches in which all values defined as relevant for a batch are within specification • Number of batches within specification for one specification value		**Target vs. actual evaluation and display of quality parameters** • Warning, when analysis values outside tolerance	**Adjustment of maintenance data** • Maintaining service cycles	**Stock levels** • Stock overview – current levels or levels at an appointed time • Stock location history • Batch tracking • Material inventory movement **Material movement** • Main product stream from malt receiving, usually by truck, through brew-house, fermentation, filtration, up to handover to bottling lines • In rare cases also the link from production to the bottling lot at the filling machine • Tracking of by-products (yeast) can make sense if they are to be sold on to the pharmaceutical or food and beverage industries
	Analysis	**Analysis plan versus actual** • Analysis of timing discrepancies • Comparison of production requirements with comparable operating data **Evaluation of alarm-, event- and message lists** • Analysis of alarms, events and messages from the DCS **Generation of electronic batch records** • Timed progress of the batch • Trend plots of quality-relevant measurements **Material tracking or material genealogy** • Overview: which ingredients were used in a batch? • Overview: in which batches was a particular ingredient used? **Evaluation of statistical analyses** • KPIs • OEE analysis • Process analysis with Online Analytical Processing (OLAP) based on MES data		**Analysis and documentation of quality data** • Generation of statistical evaluations: KPIs • Variance of quality data • Indication of quality progress over long and medium term production **Quality monitoring, evaluation and documentation of** • Quality-relevant discrepancies	**Analysis and documentation of maintenance data** • Run times, personnel expenditure, problematic equipment • Parameters • Ascertaining the number of event-driven maintenance measures (costs, production losses) • Resource needs and costs	**Analysis and documentation of inventory data** • Consumption, stock levels • Correlation with operating data • Degree of ingredient utilization • Evaluate delivery integrity (due date, amount)

Table 3: MES modules for activities in food and beverage production according to the process model

5.3 Refineries and petrochemical industry

Comprehensive and self-contained software systems for management and controlling the economic aspects of a production plant, which are widely implemented in the regulated process and manufacturing industries, are not extensively used in refineries and the petrochemical industry. Nevertheless, functions like production planning and scheduling, optimized utilization of resources as part of process management, securing plant availability, and quality control are fundamentally important. Thus, these industries also use MES functionalities, although not in a single software environment.

There is a selection of specifically tailored applications available to handle the specific tasks, some of which are integrated and communicate with centrally managed and openly accessible databases.

The purpose of these applications is improved operational performance, greater transparency of running procedures, and identification of production alternatives. Generally accepted standards for operational processes based on international norms are increasingly used in this industry, too. However, at this time, fully standardized software solutions and consistently efficient procedures are not yet available. The need to link production and enterprise management is becoming increasingly urgent, especially in light of the changes in global demand and unsettled economic conditions. Therefore, this link is increasingly implemented.

5.3.1 General description of typical operations

The operational process includes long-term planning with a time frame of months or years (generally based on linear programming models), short-term production planning and scheduling, production management, process control and monitoring, material and energy management as well as procurement and quality assurance. Figure 10 provides an overview of the entire value chain.

The long-term LP models with time frames of one month to five years (depending on the task which may range from production scheduling to investment planning) use ERP-generated demand forecasts and additional raw material data from a crude oil database. The LP models optimize an objective value –

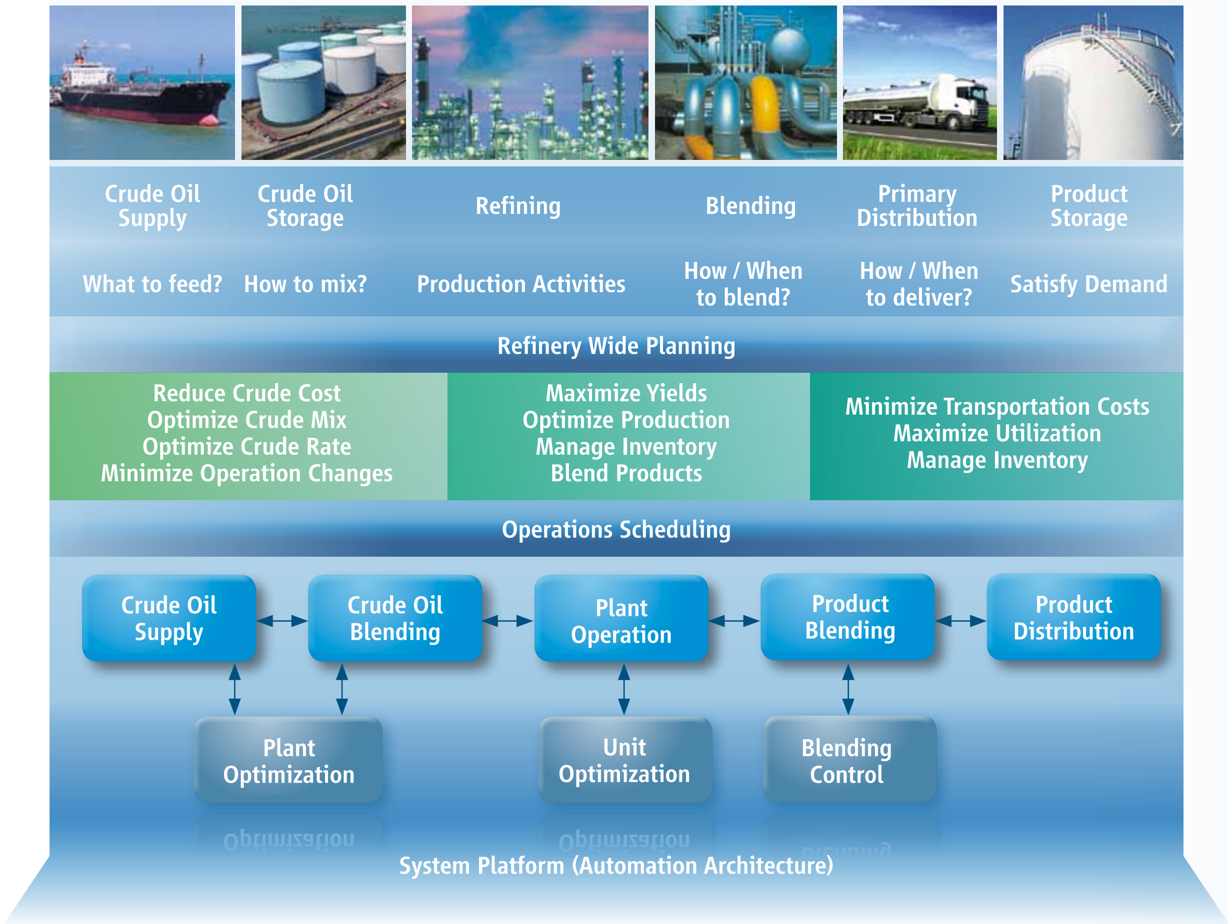


Figure 10: Refinery value chain

usually profitability – which depends on crude oil data, market-driven economic requirements, and present operational constraints. In addition, non-linear simulation models and so-called flow sheet simulators are used for further calculations. The available tools allow interconnected simulation of different production areas. The result is optimized selection of suitable crude oil grades for specific refineries with regard to the required product mix, material and energy requirements as well as CO2 emission. The delivered material is verified (LIMS) and included in inventory management. Based on these data, crude oil disposition, allocation to process units, and subsequent product blending is scheduled. The scheduling data are then transferred to process control tools and systems which use the data for optimized operation strategies, for example based on Advanced Process Control (APC).

In addition to acquiring and storing raw materials, procurement is also responsible for keeping spare parts available to operations. Simultaneously, quality control checks and documents the raw materials as well as intermediate and finished products. Storage and shipment of products are planned, monitored, and documented for invoicing purposes using additional tools.

All areas of a refinery supply material, process, and event data about production processes which are generally stored in a central database. The central database allows not only comprehensive documentation, but also timely analysis and inferences for further optimization of operations.

Production scheduling requires:

a) Specification and analysis of demand for a time frame of typically 1 to 3 months for a LP model. The LP model is supplied with ERP as well as other data.
b) A crude oil database with information about available raw materials.
c) The creation and optimization of supply and production plans for several refineries or petrochemical plants (supply chain management).

This planning results in the crude oil selection for one or more refineries.

Production preparation requires:

a) Medium-term planning (1 to 15 days) and scheduling crude oil allocation to a refinery and specific units at that location. Requirements for component blending (multi-period, multi-product) based on the LP model results. The goal is the optimum utilization of equipment and capacities.
b) Transfer of data from ERP.

Production execution requires:

a) Conversion of scheduled requirements into setpoints for process control (APC software or process control system).
b) Implementation of plan instructions for process units and software modules for blending of components.
c) Control of processes including resource optimization (equipment, energy, material).
d) Blending management software, process control systems, and APC software.
e) Planning of material utilization in the LP model which is corrected in real-time by updated operations data.
f) Acquisition, calculation, and display (KPI) of energy consumption. APC can optimize using an objective function.

Production evaluation requires:

a) Collecting and archiving the plant-wide production data including laboratory data in a long-term database.
b) Analysis of production and laboratory data, reporting, and feedback of data to the planning models.
c) Comparison between monthly plan or a recalculated plan (backcast plan), and actual production.

5.3.2 Operations supported by MES functions

Activities	Areas			
	Production	**Quality**	**Maintenance**	**Inventory**
Resource Management	**Long-term planning of refinery loading** • Examine current and anticipated market requirements and allocation of existing capacities at enterprise, site and production level • Long term planning of material supply for the enterprise and individual plants while considering availability of feedstock as well as material and transport costs (strategical, tactical and operational supply planning) • Long term planning of required assets in the operations according to general market needs and actual customer requirements • Optimization of parameters such as feedstock procurement, product demand, distribution costs, distribution capacities, production capacities, manufacturing costs and stock levels • Minimization of operational adaptations • Personnel planning	**Collection and evaluation of feedstock characteristics** • Feedstock analysis and use of a crude oil database; resulting in yield and quality data of available crude oils • Input data for LP models or other simulation tools in the supply chain	**Ensure timely availability of critical assets with long-term planning** • Planned shutdown and maintenance of plant equipment • Situation-oriented purchasing of spare parts • Plan personnel in line with anticipated production phases	**Demand and capacity planning for personnel, material and equipment in line with long-term plans** • Adjusted stock levels • Orders, (temporary) capacity increases
Definition Management	**Analysis of required product quality and determination of necessary production and recipe parameters**	**Specification of product quality and deadlines** • Order-related inputs	**Define plant maintenance cycles and criteria** • Maintenances lists (equipment, personnel) • operation related adaptations	**Determination and administration of economic Inventory Indicators**
Detailed Scheduling	**Scheduling of operational facilities and production assignments** • Objective is to maximize performance and profit, with logistics, quantity and quality as scheduling criteria • Minimize operating costs while maximize yields and utilization • Consider order data, feedstock receipts and available piping routes • Schedule crude oils and blends in refining, assignment of plants, units and production routes • Schedule components for product blending; distribution to terminals • Planning and allocation of energy and utilities • Transfer data to logistical and operational applications • Crew management	**Enhancement of logistical planning with quality criteria** • Quality correction of logistics scheduling; feedstock characteristics and operational parameters are converted into yields, attributes and operational limits	**Moving planning data into maintenance modules**	**Moving planning data to inventory modules**
Dispatching	**Optimum allocation of operational equipment according to scheduled and current operations data** • Allocation for optimum feedstock blending (blending materials, routes) • Optimum selection of material routes based on availability of equipment • Allocation for optimum blending of commercial products including managing material transfers • Entry, control and monitoring of quality parameters • Routing for blending components and product tanks	**Analysis and adjustment of blend qualities**	**Use CMMS to help organize the timing of maintenance tasks in line with deployment and resource plans**	**Planning / adjustment of resources in line with current demand**
Execution Management	**Optimum management of production units** • Stable, consistent plant and unit control strategy (control system) • Automated or semi-automatic operational procedures (consistent operations and quality, less abnormals) • Administration of variable operational parameter sets for plant control strategies • Optimization of operational parameters of production units (MPC) • Coordination of unit parameters for optimum total operation (simulation) **Product blending according to specification** • Setpoint control of blending parameters • Avoid improving quality beyond specification requirements (give-away) • Stable blending ratio control	**Blending quality** • Measurement and documentation of adjusted product quality (on-line, lab)	**Plant Asset Management (PAM)** • Collecting operating equipment parameters • Feed into planning of maintenance activities • Interface to inventory levels and purchasing of spare parts and materials **Performing maintenance activities in line with plant needs** • Monitoring and adjustment of plant asset service cycles (process-related Asset Management) • Control loop performance monitoring to proactively determine actions required on field devices and valves	**Adjustment of inventory data based on plant conditions**
Data Collection	**Collection and visualization of current process and event parameters (control system)** • Use of current and recent (days, weeks) operating parameters which have been archived in components of the control system by operators in the control room **Long term archiving** • Collection and archiving of plant-wide operating data for current or future analysis; typically used outside the control room	**Definition, collection and storage of general quality indicators for production laboratory data collection** • Collection and storage of analysis data from the lab. (LIMS)	**Updating maintenance data as a result of plant changes**	**Updating stock level data in line with plant changes**
Tracking	**Target vs. actual evaluation and display of operational parameters under live conditions**	**Target vs. actual evaluation and display of quality parameters under live conditions**	**Adjustment of maintenance data, possibly according to defined mechanisms**	**Adjustment of inventory data, possibly according to defined mechanisms**
Analysis	**Analysis of plan versus actual** • Comparison of planning data from the LP model with achieved operational data • Correction of the planning models with current data **Evaluation of archived production parameters** • Analysis and documentation of the economic aspects of operational parameters • Analysis and documentation of abnormal situations in plant or units • Analysis and documentation of correlations of operational parameters **Evaluation of alarm-, event- and message lists** • Analysis and documentation of alarms, events and messages from the control system **Evaluation of archived event sequences** • Analysis and documentation of Sequence of Events data (SoE) after abnormal situations	**Analysis and documentation of quality data and key performance indicators (KPIs)**	**Analysis and documentation of maintenance data** • Run times, personnel expenditure, technically problematic areas, costs • Correlation with operational parameters and operational areas	**Analysis and documentation of inventory data** • Consumption, levels • Correlation with operational data

Table 4: MES modules for refineries and petrochemical industry according to the process model

5.4 Chemicals / specialty chemicals

The chemical and specialty chemical industry is characterized by a wide variety of processes, products, and plant types. A given plant may use continuous and semi-continuous processes as well as typical batch processes with a range of less than ten to several hundred products or product variants product formulas.

This results in a broad range of requirements on the respective plants, the necessary automation concepts, and the process complexity. The requirements and implementation of the associated MES modules vary accordingly.

Especially in multi-product plants, parallel production in possibly identical plant sections with flexible production lines is available. In dedicated plants, a product change may require equipment or piping changes. The ingredients are usually added from tanks using pipes, or from containers (drums, big-bags, etc.). In this type of plants, software for batch management including modularly structured recipes, coordinated process control, and flexible unit allocation has become a commonly used standard.

In continuous processes, product changes tend to be rare. Most ingredients are added using pipes or silos. Thus, batch-oriented processing and production documentation are generally limited to preceding or succeeding phases.

Figure 11 provides an overview of alternative plant structures and their level of complexity.

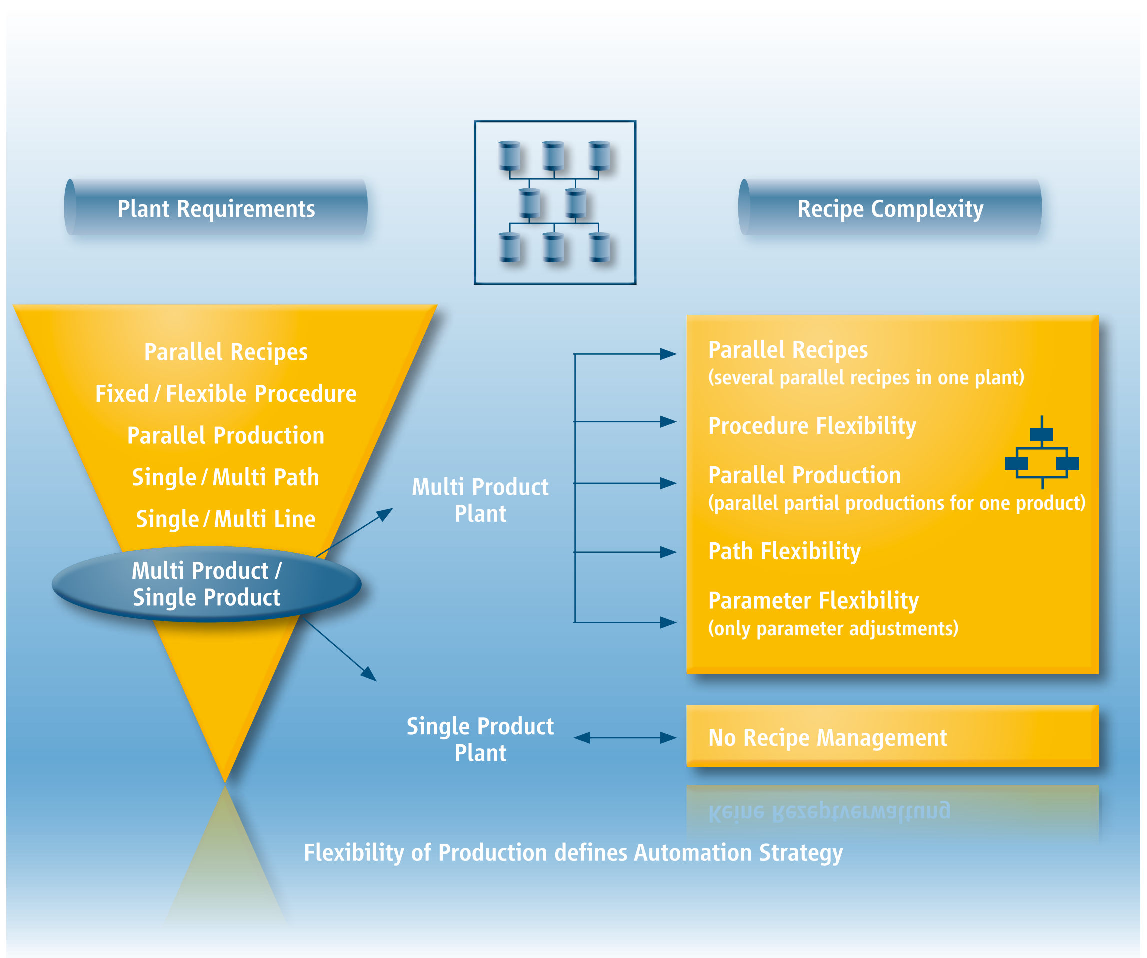
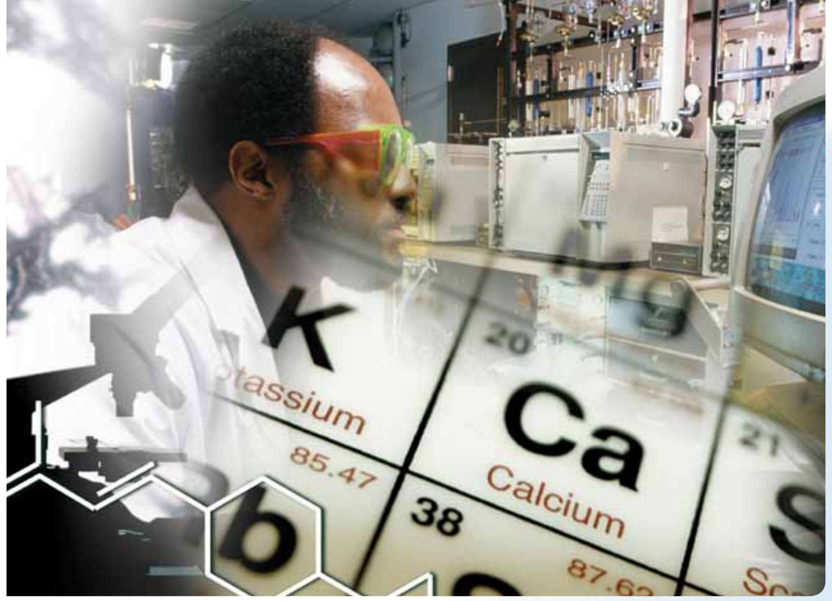


Figure 11: Chemical / specialty chemical plant types



Recipe control is increasingly used also for less complex plant structures with a limited range of product variants, for example plastics production with different quality grades. This simplifies the adjustment of process parameters and enforces a structured and consistent implementation. The production can be evaluated with regard to process units and produced batches. Overall, recipe control provides better overview and transparency of the operational correlations.

Especially for enterprises with multiple locations, or multiple linked production plants at the same location, MES tools very effectively plan, monitor, and control the entire supply chain.

5.4.1 General description of typical operations

Because of the variety of different plant types in the chemical and specialty chemical field, there is no typical operational process. However, the role of specific elements in specific operational phases can be shown in general.

In general, the first element is the analysis of the market demand which in turn is used for definition of production planning requirements (make-to-order).

Production orders resulting from planning are dispatched as campaigns by operations, and divided into individual batches and assigned to available units. Checking the availability of ingredients and the required capacity for product storage and shipment are also part of dispatching. For complex plant structures and production processes, scheduling tools are used which mimic the traditional planning boards on computer screens and provide dynamically updated information to the dispatcher station. At the same time, manual dispatching, assignment, and monitoring of resources are still common in less complex environments.

The higher the product diversity, the more important becomes the systematic use of tools for supply chain management from an economic point of view. Especially in multi-product plants, these tools schedule and monitor the raw material supply and inventory with specific consideration of market availability and cost.

Based on a product's manufacturing specification, the procedure is carried out automatically (recipe), semi-automatically (recipe processing with manual interaction) or completely manually. Modular recipe software which can be implemented as an MES module or as a function in the control system supports flexible, transparent, and self-documenting operation even for complex processing requirements and plant structures.

Continuous monitoring of the quantity and composition of ingredients and integrated quality measurement of intermediate or finished products support smooth and specification-compliant production. This may require specifically prepared analyses involving the laboratory as well as implementation of a Laboratory Information Management System (LIMS). A LIMS contains directives for taking and evaluating samples, stores the collected data, and transfers the data to plant-wide information systems.

Contemporaneous evaluation of batch operations is supported by specific MES modules. These modules process, visualize, and log the batch, analysis, and process data in relationship to the recipes and the plant structure.

Production scheduling requires:

a) Analysis of market demand for particular product groups or products.
b) Explaining possible applications of the plant's products to potential users.
c) Adjusting product characteristics (typical parameters, grades) and manufacturing requirements (quantity) for production.
d) Evaluation of order data (profitability, delivery date, plant allocation conflicts) and providing alternatives if necessary.
e) Planning and procurement of ingredients.
f) Scheduling and allocation of plant capacity.
g) Maintenance planning including scheduling of maintenance work and procurement of spare parts based on operating hours.
h) Planning of shipping (storage, tank capacities, and transportation routes).

Production preparation requires:

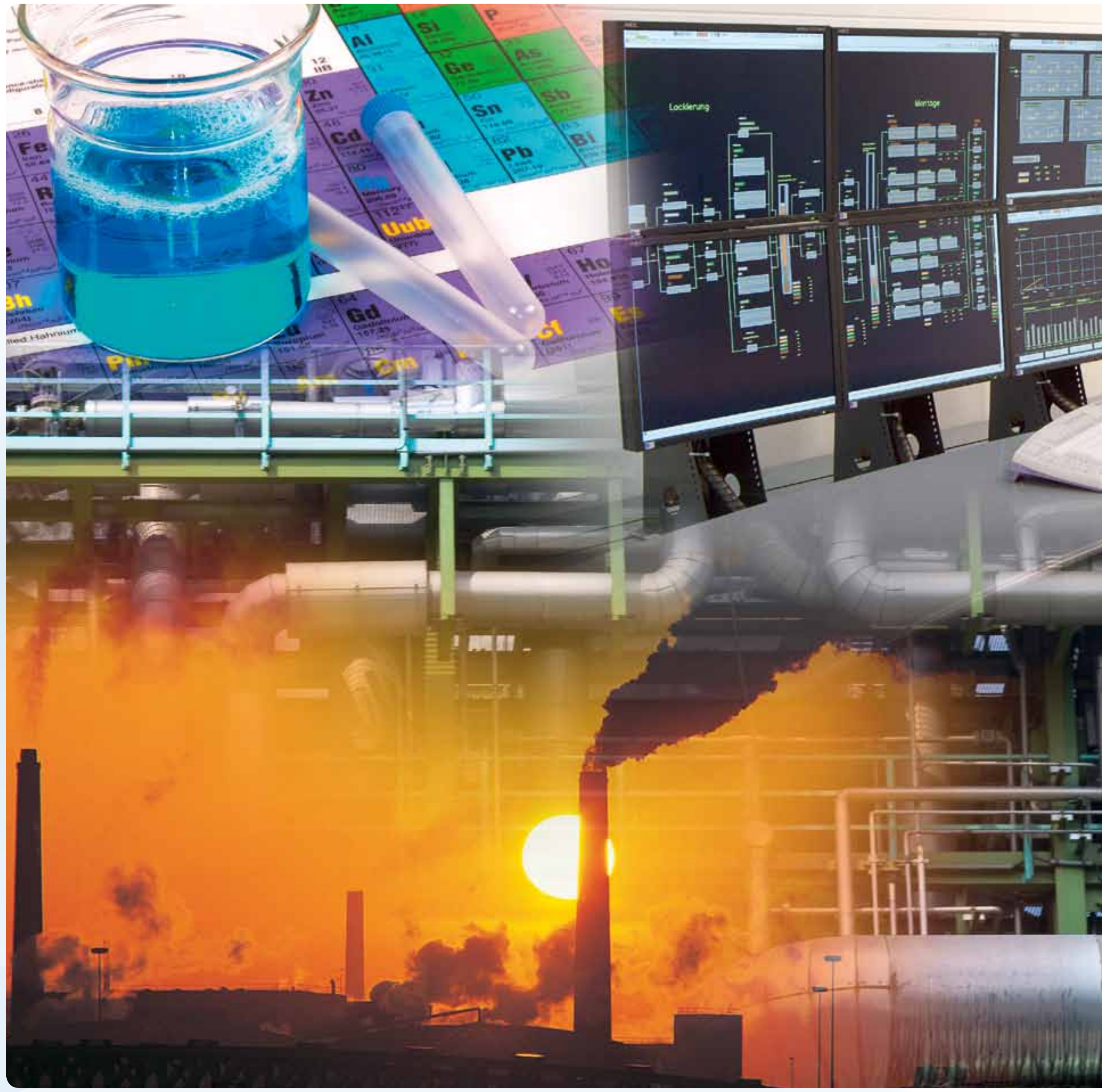
a) Generation of internal production orders including quantity and quality specifications.
b) Recipe changes (procedures, parameters) based on product requirements.
c) Scheduling of production units (production lines, units, containers).
d) Dividing campaigns into individual batches based on production unit capacities.
e) Scheduling ingredients and ordering more if needed.
f) Dispatching of production personnel based on the required qualifications.
g) Dispatching of spare parts as forecast for scheduled production.

Production execution requires:

a) Receiving production orders (recipes, setpoints, instructions, etc.) from production preparation and scheduling.
b) Running the process in line with product flexibility criteria (variable recipes) and economical considerations (energy consumption, quality, and yield).
c) Monitoring and control of the process using automated recipes or manual manufacturing procedures. The degree of plant automation and the implementation of processing functions using control system components can vary significantly depending on local preferences, the existing automation infrastructure, or particular company or product related constraints. The increasing transformation of execution systems into single comprehensive logistical and technological systems with vertical and horizontal integration, as well as ERP, receiving, production, inventory, laboratory, and shipping, defines the tasks for MES.
d) Process stability and safety.
As a matter of principle or preference, safety-related functions and basic automation requirements are not implemented in MES, but in the basic control system architecture. For additional safety, this architecture may use redundant systems.
e) Monitoring of levels in containers.
f) Acquisition of product quality data (laboratory, in-line) which may result in adjustment of operating parameters or individual procedures:
- Laboratory analysis after taking samples in operation
- In-line analysis with special analyzers
- Calculation of indicators.

Production evaluation requires:

a) Acquisition and archiving of process and analysis data including production requirements (e.g. in recipes).
b) Analysis of production data and performance indicators. Depending on the type of process or procedure, the analyses may be based on process units, batch identifiers, or process data.
c) Logging of process and batch data for product tracking for company use and regulatory compliance.
d) Feedback of analyses into plant scheduling and product specifications (recipes).
e) Transfer of selected feedback information to enterprise planning.



5.4.2 Operations supported by MES functions

		Areas				
		Production		**Quality**	**Maintenance**	**Inventory**
Activities	**Resource Management**	**Market analysis and delivery capacity** • Demand forecasting models for product groups and selected products • Order evaluation (customer evaluation) • Evaluate ability to produce and deliver (capacities, due dates, quality) • Examining production alternatives (sites, capacities, costs) • Optimization of raw material purchasing, distribution costs and capacity, production capacities, manufacturing costs and inventory • Assigning production orders to sites; minimizing plant changes and adjustments • Long-term planning of assets required in the plants in line with general market demand and actual customer requirements **Production master plan (supply chain)** • Tactical and strategic planning • Planning for consumables • Master allocation plan • Preplanning of material streams (feedstock, products) **Reporting of production history on planning level** • Dates of product delivery, quantities, characteristics **ERP interface** • Ordering data, consumption data, delivery data...		**Requirements of product attributes** • Collection of requested quality data • Comparison with plant production capabilities **Collection and evaluation of feedstock attributes** • Analysis and storage of relevant feedstock attributes • Evaluation (acceptance or rejection) • Evaluating the influence on production requirements, adjustment of parameters may be necessary	**Planning the timely availability of assets required for uninterrupted operation** • Planning for equipment downtime and repair (cyclical) • Envisage event-driven maintenance • Plan personnel to coincide with expected operational phases and short-term needs	**Long-term planning of demand and capacity for material and equipment** • Strategic, tactical and plant supply planning • Adjust stock levels in line with production planning • Procurement, envisage possible (temporary) capacity increases
	Definition Management	**Clarification of order data** • Quantities (lot sizes), qualities, due dates **Determining plant limitations** • Run times, capacity limits, alarm limits **Definition of production procedures / recipes** • Create and store product-specific requirements **Subsequent adjustment of specification data after production**		**Specification of material characteristics** • Quality of feedstock • Test and release procedure for feedstocks • Product qualities • Product checks and release procedure **Quality data adjustment** • Mechanisms for order-related Adjustment • Avoiding excessive product qualities	**Provide plant maintenance criteria and intervals** • Organize procedure for technical failure reports and maintenance orders • Maintenance orders (plant equipment, work stages, group assignments) • Operation-dependent adjustments (use run time indicators and load profiles) • Define KPIs for assets	**Definition and management of economic inventory indicators** **Define provisions for stock levels (backup quantities)** **Procedure for violation of stock limits**
	Detailed Scheduling	**Scheduling plant equipment and production assignments** • Transfer of production orders from ERP or Supply Chain Management software • Scheduling criteria: logistics – quantity – quality; typical objective function = f (profit, performance); minimize operating costs; maximize yields and utilization • Considering order data, feedstock receipts and available pipe routing • Splitting campaigns into individual batches • Assignment of plant production units (production lines / paths, units, vessels) • Short-term plan adjustments as needed • Planning and allocation of material, energy and utilities • Interface to logistical and operational applications • Display of plant allocation and production status		**Logistical planning adjustments in line with given quality criteria** • Adjustments to material characteristics and plant parameters • Scheduling analyses during production • Feedback of analysis data to further optimize quality definitions	**Moving planning data into maintenance management modules**	**Moving planning data to inventory management modules** • Material disposition according to real production quantities
	Dispatching	**Optimum allocation of plant equipment in line with scheduled and current plant data** • Automatic transfer of requirements from Detailed Scheduling or via operator action • Adjustment of material routing depending on equipment status, as necessary • Releasing start of production • Provision and control / monitoring of quality parameters		**Checking material characteristics**	**Planning and adjusting resources in line with current demand**	**Planning / adjustment of resources in line with current demand**
	Execution Management	**Optimum management and control of production units** • Stable, consistent plant and unit control strategy (control system) • Automatic or semi-automatic operational procedures with or without recipe control (consistent procedures and quality, less abnormals) • Administration of variable parameter sets for plant control strategy (recipe contents) • Optimizing the control behavior of critical production units (APC) • Automatic path routing		**Product quality** • Product quality measurement during running production • Avoid quality better than that required by the specification (give-away)	**Plant Asset Management (PAM)** • Collecting operating equipment parameters • Feed into planning of maintenance activities • Interface to inventory management and purchasing of spare parts and materials **Performing maintenance activities according to operational needs** • Monitoring and adjustment of plant asset service cycles (process-related Asset Management) • Control loop performance monitoring to proactively determine actions required on sensors and actors	**Adjustment of inventory data based on plant conditions**

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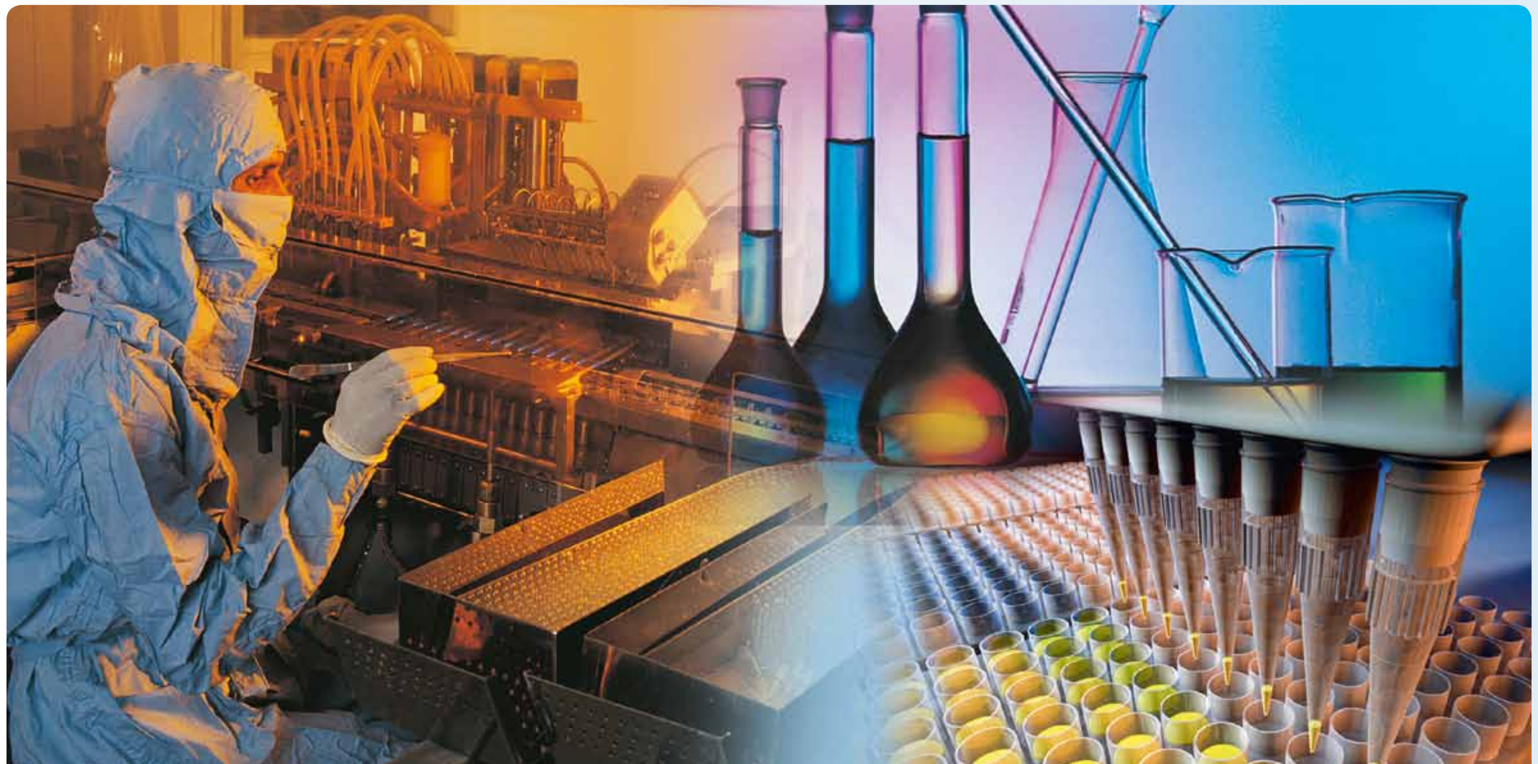
		Areas				
		Production		**Quality**	**Maintenance**	**Inventory**
	Data Collection	**Collection and display of current process and event parameters (control system)** • Use of current and recent (days, weeks) operating parameters which have been archived in components of the control system by operators in the control room • Comparison of selected process data with corresponding historical data during live production and appropriate parameter adjustment (Golden Batch principle) **Long-term archiving** • Collecting and archiving plant-wide operating data for current or future analysis; typically used outside the control room • Evaluation with respect to plant model (units), recipe structures, production event data, continuous production data • Flexible analysis queries in line with current needs; logging		**Definition, collection and storage of general quality indicators for production** • Laboratory data collection • Collection and storage of analysis data from the process or lab. (LIMS)	**Updating maintenance data in line with plant changes**	**Updating stock level data in line with plant changes**
	Tracking	**Target vs. actual evaluation and display of operational parameters under live conditions** • Comparison of selected process data with corresponding historical data during and after live production and appropriate parameter adjustment (Golden Batch principle)		**Target vs. actual evaluation and display of quality parameters under live operating conditions**	**Adjustment of maintenance data, possibly according to defined mechanisms**	**Adjustment of inventory data, possibly according to defined mechanisms**
	Analysis	**Analysis plan versus actual** • Comparison of production requirements with comparable current operating data • Correction of the planning models with current da **Evaluating archived production parameters** • Analysis and documentation of operational parameters from the plant, batch structure and process against operational, organizational and economic aspects • Analysis and documentation of abnormal situations in plants or units • Analysis and documentation of correlations of operational parameters **Evaluation of alarm-, event- and message lists** • Analysis and documentation of alarms, events and messages from the control system, selected from a batch or equipment viewpoint, as needed **Evaluation of archived event sequences** • Analysis and documentation of Sequence of Events data (SoE) for marginal conditions		**Quality data and Key Performance Indicators (KPIs) - analysis and documentation**	**Analysis and documentation of maintenance data** • Run times, personnel expenditure, technically problematic areas, costs • Correlation with operational parameters and operating disziplins	**Analysis and documentation of inventory data** • Consumption, levels • Correlation with operational data

Table 5: MES modules for chemical and specialty chemicals industry according to the process model



5.5 Serial production (automotive industry and suppliers)

There are two basic categories of serial production:

1. Line manufacturing with completely interlinked components for production of one or more products as well as product variants.
2. Lot manufacturing, in which the product streams between the individual production stations may be routed differently depending on product characteristics.

Depending on the industry and the specific products (white goods, brown goods, electronic components, small mechanical parts, etc.), the two types of serial manufacturing described above are combined as needed.

Since the automotive industry is used as example for serial production, the following explanations distinguish between Original Equipment Manufacturer (OEM, automobile manufacturer) and supplier which is typical for this industry.

OEM:
The state of the art allows mixed production of several car models on the same assembly line with a very large number of variations. For example, it has become common that an assembly line produces no identical cars for an entire month.

Supplier:
In view of the increasing number of product variants and the pressure to reduce production costs, suppliers must combine flexible manufacturing systems with the earlier „single-product assembly line“ concept. This requires increasing flexibility while providing high quality and throughput.

5.5.1 General description of typical operations

OEM perspective of operations

Production scheduling
In multi-variant serial manufacturing, production equipment is usually completely interconnected. Production planning focuses on the entire serial production instead of individual machines. Bottlenecks are identified and resolved only during unit allocation. The cycle time is determined by the production step with the longest duration of stay at a working station.

The most important aspect of production scheduling for serial manufacturers is the correct sequencing of different product variants in order to accomplish as even as possible utilization of all working stations. One week to three days before start of production of a car body, the production sequence for products with different characteristics is determined. Complex and less complex products are alternated.

The criteria of this sequence scheduling vary depending on the production area:

- Body construction: alternating of complex and less complex products (complexity and feature mix).
- Paint shop: scheduling of products with the same attributes (color) in blocks.
- Assembly: similar to body construction and partly linked to Just-in-Sequence (JIS) supply of parts.

Body construction and especially body assembly is characterized by sophisticated material supply strategies. Body parts are mostly supplied in-house (press shop), while components required in the assembly area are generally delivered by external suppliers.

After production order generation, the suppliers receive requests for required quantities and construction variants. During the last phase of production sequencing, the requests are finalized depending on the applied strategy, for example Just-in-Time (JIT) or Just-In-Sequence (JIS).

Production preparation
The suppliers are responsible for production preparation of requested materials. Using a sophisticated and precise logistics chain, material to be processed or installed is available to production on-time and in-sequence.

Other materials are collected from storage and assembled based on production orders. Automatic or semi-automatic storage techniques like Pick-to-Light support the personnel by locating the required material and indicating the required quantity.

In serial manufacturing, personnel requirements are determined by the number of working stations (i.e. by the plant structure) and not by production orders. Scheduling of personnel resources is defined by the number of shifts per week and recorded in form of shift plans.

Since the assembly stations are completely interconnected, they are not individually scheduled.

For fully automated working stations, for example robots for body construction, production preparation must ensure that all production programs required for different variants are available in each station. Product variants are identified by identification numbers (vehicle ID or skid ID) which are used to load and execute the appropriate manufacturing program.

Production execution
In series production, production execution starts with the entry of the production order in the appropriate systems (request management, commissioning, etc.). A production order becomes visible as an object when the raw body is created in body construction. At this point, the vehicle ID is created, even though the vehicle is associated with a customer order at a much later point, possibly not before final assembly. Production scheduling and preparation ensure the supply of materials for serial production.

During production, facility monitoring is vitally important. The availability of plant has to be ensured (no repairs), production parameters must remain within specified limits, and product quality must comply with product specifications (tolerances, gap sizes, surface quality, etc.). In addition to sensors for process parameters such as pressures, currents, voltages, temperatures, and sizes, quality monitors are installed at relevant locations in the assembly line to verify the specified quality (e.g. light tunnel to determine paint surface quality). Furthermore, spot checks are performed and evaluated in detail.

The collected production and quality data sets are assigned to a product which is partly required by law. Even after delivery, the collected data are maintained by the manufacturer and linked to the product ID (usually the chassis number).

The vehicle assembly (motor, transmission, chassis, and interior) is still characterized by manual interaction. Detailed assembly plans are generally printed as lists and attached to each vehicle, providing step-by-step guidance to assembly workers. For any used material with serial numbers, the numbers are collected by scanner, keyboard, etc. and assigned to the vehicle.

Using the production feedback, production monitoring tracks the assembly status of individual production orders and controls the supply of materials for subsequent working stations.

Production evaluation / tracking
Collecting the product, quality, and production data listed above allows precise tracking of various key production parameters.

During ongoing production, the target and actual production figures as well as the number of finished and quality-approved units is displayed by shift.

Furthermore, this information is used to continuously monitor plant availability and production/operations costs in combination with output (Figure 12). If certain limits are exceeded, targeted analyses are performed in order to identify weak points in production and address them using Continuous Improvement Processes (CIP).

Supplier's perspective of operations

For the automotive supplier industry and automotive OEMs, operations vary in several basic areas.

In the supplier industry, a large number of companies operate with classical serial production or order-based production of small series. A product is produced in different variants and partly in large quantities. Unit-based sequencing as used in vehicle assembly is not required. The products are increasingly individualized using serial numbers as a result of company, product, or legal requirements, for example for comprehensive traceability.

The degree of production automation depends on the product. In particular, companies producing electronics are far more automated than companies producing mechanical components which are characterized by largely semi-automatic processes with preceding or subsequent manual steps.

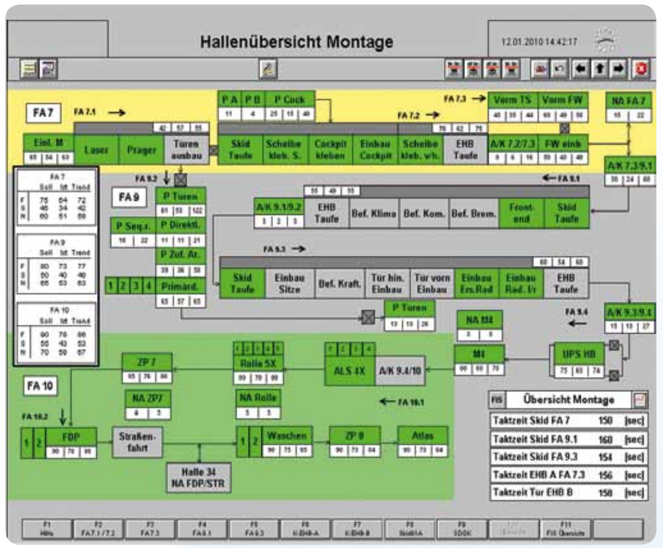


Figure 12: Overview diagram with counter values in automotive manufacturing

Production scheduling
The timed requests to OEMs in dependence on their logistical concepts, for example Order-to-Stock, JIT, and JIS provide the basis for production scheduling and control. These logistical concepts delegate the flexibility to the suppliers who must design and control production capacities accordingly. This generally precludes a complete interconnection of production systems covering multiple product stages.

Production preparation
Production preparation for suppliers is generally comparable with the characteristics described above for automobile manufacturers (OEMs).

Materials are commissioned based on orders or provided demand-driven and partly automatic in case of series production. Personnel are scheduled based on assembly line and production structures. The plans are based on demand, tasks, and the shift schedule.

The allocation of working stations is determined by production structures. Working stations are often not supplied by ongoing production, but from intermediate buffer storage. Thus, planning is driven by production orders in the ERP system.

Production preparation for fully automated processes (SMD, interconnected assembly lines, quality testing systems, etc.) must ensure that the manufacturing and testing programs required for the different product variants are prepared and can be made available automatically. Product variants are recognized using identification numbers (unique ID or serial number), and the corresponding manufacturing or testing program is loaded and executed.

Production execution
Series production begins with production scheduling and entry of a production order into the relevant systems (request management, commissioning, etc.). If products are manufactured with a serial number, it is often defined in the first stage of the process. It uniquely identifies the product and is used to determine the status of the product (order).

Satisfying production requirements and thus guaranteeing specified product quality as well as optimized utilization of production resources represent major goals. Thus, „Quality Gates" are part of the production process and are implemented by ongoing spot checks, or increasingly by 100%-checks. Faulty products are detected directly in the process and are either reworked or removed from the production line. Real-time feedback of order progress and produced quantities allow increase of order quantities or entry of further production orders in order to feed subsequent processes.

Production evaluation / tracking
Especially in areas with high quality requirements or fast production cycles, production evaluation is performed „online" during ongoing production similar to monitoring. The goal is the ability to intervene and correct early enough in order to completely meet the production requirements.

The online evaluation results and other data are used to determine the plant availability and output as well as cost of operations and production on a continuous basis. If predefined limits are exceeded, targeted analyses are performed in order to identify weak points in production and address them using Continuous Improvement Processes (CIP).

The standardization of processes and systems for plant operations is a key factor in satisfying stringent performance requirements efficiently. In addition to global aspects regarding enterprise standards, it is important to incorporate local preferences, language and cultural aspects, as well as plant-specific characteristics.

Demand-driven production strategies are necessary to respond flexibly and economically to fluctuating market requirements. Fast and flexible reaction to changes and close communication with neighboring systems (such as level 4, level 2, JIS, JIT, quality, and maintenance) are key success factors.

High availability of information also allows targeted and economical maintenance. Routine checks become unnecessary or are scheduled based on operational events.

Furthermore, increased regulatory requirements generally impose demanding specifications on data acquisition and reporting.

Comprehensive reporting functions and the capability to retrieve relevant and correct data within shortest time frames are essential for all quality and environmental issues. Detailed documentation of quality-relevant data is the key to allocating the cost of liability risks and warranty claims to the responsible parties.

The following table provides an overview of topics relevant for operations including detailed analysis regarding the areas production, quality, maintenance, and inventory management.

5.5.2 Operations supported by MES functions

		Areas				
		Production		Quality	Maintenance	Inventory
Activities	Resource Management	**Planning and monitoring of** • Human resources of according to request and qualifications • Production resources (tools, machines, conveying equipment, material and parts supply facilities, JIS/JIT/KanBan) • Production material (basic parts, assembly and add-on parts) • Electricity supply, data networks, PLCs and software		**Planning and monitoring of** • Personnel • Test aids, software and statistical methods • Documentation • RWM (Rework Management)	**Planning and monitoring of** • Machine data • Personnel • Maintenance guidelines and documentation methods • Tools • Spare parts	**Planning and monitoring of** • Storage resources • Storage equipment **Information exchange with warehouse management systems concerning inbound and outbound stock movements**
	Definition	**Defining** • Product master data • Production machines, production programs • Production data, production sequences, production flows • Test specifications and software **Specifications are usually generated in level 4 systems (preferably PLM or possibly ERP, CAQ)**		**Defining** • Required quality criteria • Appropriate test procedures and processes	**Setting up** • Maintenance procedures • Maintenance cycles	**Establishing** • Warehouse strategies
	Detailed Scheduling	**Converting manufacturing orders from ERP in sequences ready for serialized production consideration of manufacturing bottlenecks** • Personnel • Availability of machines and tools • Material supply (KanBan Management, Car Kit Management)		**Planning quality assurance measures with the goal of** • Reducing quality variations • Avoiding of rework and scrap	**Planning of maintenance activities checking availability of** • Maintenance plans and programs • Personnel • Material	**Announce logistical events to connected supply chain partners** Potential disturbances in the overall production process must be clarified up front with supply processes (JIS/JIT) and sub-assemblies
	Dispatching	**Approval of** • Manufacturing orders and their associated sub-orders • Orders on suppliers **Allocation of buffer areas**		**In-process dispatching of** • Quality checks • Collection of quality data	**Assignment of** • Maintenance orders	• Warehouse orders • Kitting orders
	Execution Management	• Management of production orders • Management of production equipment • Transfer and display of Electronic Work Instructions • Monitoring target vs. actual quantities • Ensuring material supply • PMC (Production Monitoring & Control) – monitor production equipment status (ensure availability)		• Test for specification conformity	• Executing, monitoring and documenting maintenance orders	• Executing inventory and kitting orders • Stock level checks • Estimation of stock turnover • Empties management
	Data Collection	• Signal status from automation level • Machine allocation, completion signals, material consumption etc. (automatic or manual – plant data collection, barcode, RFID…) • Machine data, status, process values		• Personnel, production software versions, products, carriers and assembly parts to ensure complete genealogy for subsequent tracing in case of warranty claims • Quality criteria (general product features and assembly work subject to mandatory documentation, e.g. fitting airbags)	• Machine running time, strokes, cycles etc. • Completed service and maintenance activities • Documentation of maintenance activities	• Products • Transport equipment
	Tracking	• Production quantities for target-performance comparison • raw materials and add-on parts • Vehicle identification for cycle, line and buffer control		• Quality criteria to sustainably ensure a level of quality (internal/external) • Assignment of process, machine, material and quality data to products	• Compliance with service cycles • Executing maintenance orders • Maintenance expenses (material, personnel, time) • Evaluating effects and/or constraints on production	• Warehouse and material movements • Violation of inventory key parameters
	Analysis	**Calculate and display** • All production-relevant key performance Indicators (KPIs) • KPIs from current production values (e.g. Add-on-Boards) **Evaluating** • Resource utilization and costs (personnel, machines, energy etc.) • Material utilization (good parts, scrap, rework) • Machine workload and availability		• Deduction of factors which influence product quality improvement or debasement • Showing quality process during the course of medium- and long-term production	• Analyzing plant availability associated with completed or preventive (planned) maintenance activities • Calculate the amount of event-driven service cases (costs, production losses…) • Maintenance optimization strategies	**Analysis and documentation of** • Logistics data • Delivery capability and quality • Consumption and • Stock levels

Table 6: MES modules for large series production (automobile manufacturers, suppliers) according to the process model

5.6 Machine/plant construction (made-to-order construction)

In this brochure, manufacturers of special machinery and industrial plants are used as examples for made-to-order construction. Small numbers or individual construction is typical for made-to-order construction. However, even with a lot size of one, manufacturers endeavor to build modular machinery and plants in order to use as many identical parts as possible.

The following examples are typically constructed by made-to-order manufacturers:
- Presses and press lines
- Combined machining centers (drilling, milling, grinding)
- Machines for tableware processing (laser, nibbling, plasma arc cutting)
- Food and beverage processing plants (milk, sugar, grain)
- Plants for extracting intermediate products from raw materials (crude oil, coal, gas)
- Plants for extracting industrial gases from air (air separation plants)

The following section describes the requirements for MES modules based on the examples mentioned above. Although this industry sector uses MES modules for production scheduling and execution, they are not necessarily comprehensively implemented. This is the case across as well as within production areas.

5.6.1 General description of typical operations

Manufacturing processes for made-to-order manufacturers can basically be divided into two main categories:
1. The production line resembles those found in serial production, in which the item being constructed (machine, instrument, component) is moved from one working station to the next. The individual stations are more or less independent of each other, which allows free selection of the subsequent station.

2. Largely localized manufacturing, meaning that the product to be built generally remains at the same location throughout its construction. Very large units or machines are typically manufactured this way. Individual parts and components are prepared at working stations such as lathes, bending machines, presses, cutting machines, or pre-assembly stations and then transported and attached to the actual product.

A prime example for combining these two methods is the aircraft industry, for example Airbus.

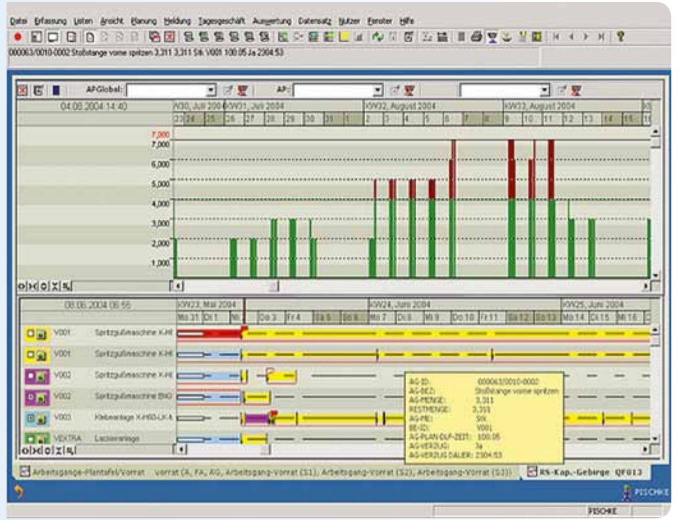
For made-to-order manufacturing, not all required process steps and equipment must necessarily be available at the same location. In many cases, production steps in the middle of the manufacturing process are outsourced.

From the MES point of view, this kind of outsourcing presents a challenge in that the object is first removed from and then reentered into the system. During the duration of the outsourcing, generally no information about the current progress state is available. This results in increased requirements for monitoring completion dates.

Building special machinery is complicated by the fact that each machine is unique. Therefore, the tools used for documentation, variant management, and maintenance management must meet special and task-specific requirements.

Production scheduling requires:
a) Identification of standard components and special assemblies.
b) Planning and scheduling of engineers (test and trial times may need to be included).
c) Schedule synchronization between existing components and those which have to be constructed.
d) Allocation schedule for machines and assembly stands (figure 13).
e) Coordinating of internal and external manufacturing (suppliers).
f) Personnel scheduling based on required qualifications.
g) Setting test and trial times including required personnel and equipment.
h) Creating documentation, particularly for special components.
i) Defining acceptance tests (SAT, FAT) including acceptance criteria.

Figure 13: Display of results of detailed scheduling of orders in a machine control station



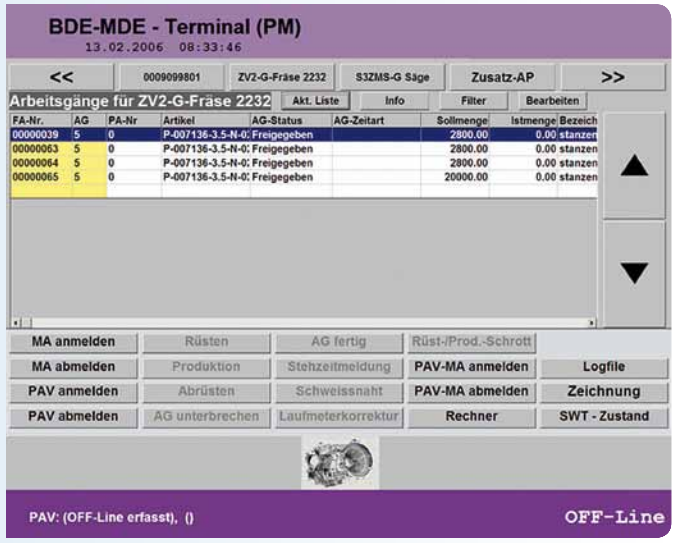


Figure 14: Typical operator interface of a production data acquisition terminal (PDA, MDA)

Production preparation requires:
a) Provision of raw materials and tools needed for their processing.
b) Supply of semi-finished products.
c) Availability of assembly stations including tools, appliances, and manufacturing programs needed for assembly.
d) Commissioning of small parts and consumable materials.

Production execution requires:
a) Availability of materials to be processed which may have been assigned to a production order via commissioning, direct inventory withdrawal, or from stocks available at machines.
b) Machine setup including tool changes, attaching necessary appliances, and loading manufacturing programs (CNC, PLC) as well as setting the parameters for semi-finished or finished materials.
c) Processing raw materials into components or semi-finished products according to manufacturing instructions (drawings, text, diagrams, etc.). Depending on the complexity of the parts, the produced quantities are collected directly via counters on the machines (MDA). In case of batch quantities, the quantity is determined by employees using terminals (PDA). Complex parts may be scanned directly into the MES via their individual serial number using bar code scanners (figure 14).
d) The traceability of produced items (e.g. for safety-related parts).
In addition to recording quantities for batches or parts, process parameters, involved personnel, and key data regarding processed materials must be collected. This is generally accomplished manually using PDA equipment.
e) Production of specified quantities. Either a statistically calculated excess amount is produced or production quality is continually determined by counting good and bad parts. In this case, quality data is collected during production using QMS (in-line QM, spot checks, etc.).

Production evaluation requires:
a) Determining the amount of good and bad parts for each lot/batch (e.g. to calculate days at hand or update of correction quantities).
b) Acquisition of quality data (for example size accuracy, material quality, and strength.
c) Reviewing quality data to establish conclusions about the wear and tear of tools and appliances, wrong process parameters, etc.
d) The assignment of series parts to higher-level components as well as possible transfer of data into PLM (Product Lifecycle Management).

The evaluation of production data usually provides information for two purposes. On the one hand, it defines the quality of the final products (or semi-finished products or components). On the other hand, it provides conclusions about the state of the production equipment. The latter can be used for maintenance, plant upgrades, or as basis for investment decisions.

The operations of made-to-order manufacturers are characterized by high flexibility due to the highly individual products and underlying customer requirements. In this industry, MES solutions must fully support the flexibility requirements without creating any obstacles. In most cases, the results generated by MES modules must be manually changeable. The manual changes or settings may affect only part of the planning while the remaining parts are processed by MES modules as planned.

The next chapter emphasizes the requirements which demand high production flexibility.

5.6.2 Operations supported by MES functions

		Areas				
		Production		**Quality**	**Maintenance**	**Inventory**
Activities	Resource Management	• Planning human resources • Production resource planning (machines / plant, assembly units and areas) • Allocation or sequencing of production orders to machines and assembly locations (PPS) • Supply of materials for processing and assembly		• Planning the deployment of measurement and test facilities	• Planning the deployment of maintenance personnel • Maintenance planning for tools and appliances	• Booking out used materials, determination and management of working stock levels • Booking in newly produced parts
	Definition Management	• Work instructions (preparation, manufacturing, assembly) • Adjustment instructions • Safety instructions • Defining required equipment • Material choice • Processing procedures • Assembly guidelines		• Test approach and methods • Test procedures • Definition of limits/tolerances	• Creating maintenance instructions and procedures • Service plans (time-based, quantity-dependent etc.) • Tool checks • Calibration • Tolerance procedures • Changing maintenance strategies	• Providing storage conditions needed for sensitive materials and components (air conditioning, clean air, etc.) • Defining storage equipment (pallets, appliances etc.) • Creating stocking procedures (vertical, flat, hanging etc.) • Return strategies for issued materials and components
	Detailed Scheduling	• Production and assembly planning in relation to technological, product- or production-specific constraints • Detailed scheduling for bottleneck machines by optimizing set-up times or other parameters specific to the task (Machine Control Center) • Planning deployment of personnel with special qualifications (time management of human resources) • Planning special measuring equipment and/or units • Manual intervention capability (priority and urgent orders)		• Assignment to measurement devices and test personnel • Planning changes because of urgent orders	• Creating deployment plans for maintenance personnel in line with qualifications • Creating service plans based on maintenance strategies (time, quantity, performance achieved etc.)	• Kitting high-value materials

	Dispatching	**Dispatching tools must be able to distribute individual manufacturing orders among several work stations (e.g. if they are equally capable), or dedicate them to particular manufacturing or assembly stations (e.g. if only they fulfill specific criteria). Examples for important tasks are**
		• Assign manufacturing orders to machines and units (forming, cutting, welding, drilling, milling etc.)
		• Assign assembly orders (assembling, filling, cleaning etc.)
				• Assigning manufacturing orders in line with test strategies
				  • Functional tests
				  • Material checks
				  • Dimensional checks
				• Assignment of test orders for tools calibration
					• Assignment of maintenance and servicing orders for machines and assembly equipment	• Goods inward and outward
						• Kitting

	Execution Management	• Status display of production quantities • Monitoring of target and actual quantities • Unprocessed orders (order stock) • Monitor and control process data (pressure, current, temperature etc.) • Processing sequences • Forwarding electronic work instructions (text, images) • Bottleneck management (material, equipment, personnel)		• Monitoring quality data • Electronic forwarding of test instructions • Direction for material restriction or release • Claim management • Damage management	• Monitoring maintenance orders • Monitoring performance variations • Forwarding necessary maintenance instructions	• Material pick-up instructions • Instructions for assembling order-related material needs (kitting) • Monitoring material levels at machines and assembly points • Calculating operating distance • Material returns
	Data Collection	• Manual or automatic collection of production quantities (PDA, MDA) • Reading serial numbers and possibly associating them with higher level components (PDA) • Establishing production orders' state/progress • Production and waste quantities • Process parameters • Stand-still times (breakdown, pause) • Operation events • Machine and personnel time recording		• In-line measuring of process parameters (MDA) • Manual assessment of quality data with spot checks (size, weight, strength, material attributes etc.)	• Types of disturbances, damage pictures • Repair times • Spare parts • Demand on human resources • Servicing aids • Consumables	• Material movements (receipts and withdrawals) • Tracking empty containers • Returns • Serial number scanning (in the case of complex, safety-relevant or high-value piece parts)
	Tracking	• Processing state, degree of completion • Material utilization • Energy consumption • Personnel deployment • Storage location • Route of order through production • Localizing production orders (examples like large facilities, external production shops etc.)		• Test data of produced goods • Process parameters • Calibration and wear & tear data	• Type of servicing • Maintenance material used • Working hours	• Material inventory movements • Material levels • Components with serial number or batch-id • Personnel
	Analysis	**Realize improvement and optimization potential** • Order-specific evaluations like dwell time in production, material utilization, personnel deployment, costs, total production time including transport and storage times • Evaluation of machines or work stations like throughput, good or bad parts, achieving targets, waiting times etc. • Overall evaluations (manufacturing areas, factories) • Generating key performance indicators (KPIs)		• Generating key information about produced goods • Key data about process parameters and calibration values • Linking product and process data to optimize manufacturing • Test parameters and results	• Effective plant availability • Stand-still times (scheduled and unplanned stand-stills) • Wear & tear and reliability analyses • Maintenance costs (material, personnel, energy)	• Estimating tied-up capital costs • Inventory turnover relative to production • Procurement/lead times • Delivery integrity (due date, amount)

Table 7: MES modules for machine and plant construction (made-to-order production) according to the process model

5.7 Paper / Metal

Paper and metal products are manufactured in complex processes which require many of the common MES functions. The production typically consists of multiple manufacturing steps between which material is stored and transported. Thus, inventory management plays an important part. The character of the manufacturing processes is hybrid: The initial processes such as pulping or blast furnace operation are continuous. They are followed by batch or campaign processes (pulp preparation, foundries). The final set of processes is discrete and batch-oriented with separating instead of aggregating production steps.

These processes are characterized by high production costs and volumes. The output consists frequently of semi-finished products destined for further processing. Thus, keeping delivery times is critical. Due to the time-intensive production chains, forecasts (campaign scheduling) are important for the heavy industry. Enterprise Resource Planning (ERP) systems, external planning modules or internal MES components are used for block or rough planning. This poses particular challenges to MES, which must partly coordinate the different process stages. The main focus of this chapter is on the initial production phases. For paper production, this includes paper machine operations up to the packing of the paper rolls. For metal production, the focus is on melt-shop operations.

5.7.1 General description of typical operations

Customer orders are received via the IT infrastructure into the level 4 systems and are typically transferred into an ERP system. From these data, larger production amounts for a given grade are collected, for example the weekly production volume, in order to achieve efficient and economic utilization of production facilities. Product or grade switching is minimized due to the generally high changeover costs. Thus, MES or manual scheduling methods are used to convert customer orders into production orders.

Production is often executed in campaigns in order to minimize costly changeover times for the paper machine or steel plant, and to optimize productivity. A particular grade or quality is produced within a campaign. Individual products appear only in subsequent phases, for example in the cutting process in paper production. Only at this phase, the desired products such as rolls or sheets in different dimensions and possibly with special coatings are finally produced.

Production scheduling requires:

a) Definition of product properties by means of inventory numbers (articles available in stock) instead of unique material numbers. This procedure is used in both industries for processing customer orders.
b) Forecasting data for campaign planning (especially in heavy industry).
c) Coordination of orders and capacities (customer orders multiple production orders), because production is executed in several steps or stages. Availability of intermediate storage capacity must also be considered.
d) Securing supplier delivery times, since the products are often intermediate products (semi-finished) for further processing.

e) Adaptation of customer orders. For example, a customer may order 10 tons of A4 sheets from a jumbo reel with certain properties as „raw material“. In the actual production, the corresponding trim planning is critical for maximizing yield. A corresponding key factor in steel production is the heat/slab design.
f) Planning of maintenance, procurement, and availability of required components, for example cores of rolls with correct dimensions for the cutting process.
g) Close coordination of scheduling with other tasks such as optimization of storage or trimming operations.
h) Information regarding production performance (figure 15).

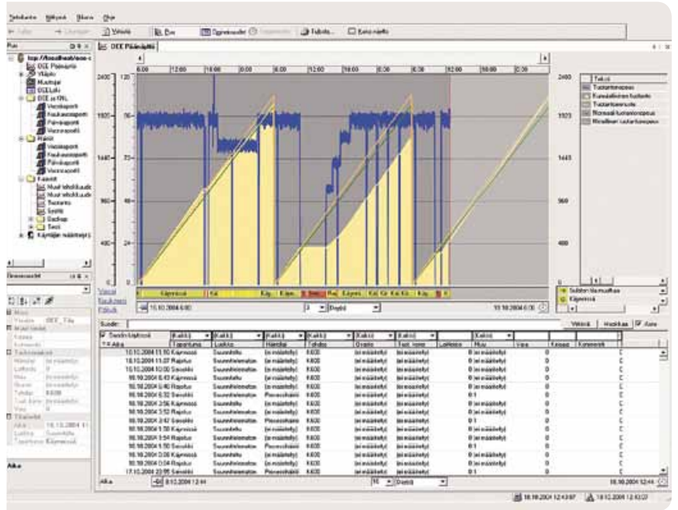


Figure 15: Production performance information (OEE)

Production preparation requires:

a) Checking if material is available, if plant status is satisfactory and available, and preparing necessary components.
b) Preparation of product changeovers including the required equipment.
c) Transport of material (cores, packaging, scrap), emptying ladles and containers, and standard cleaning.
d) Ensuring availability of required resources and correct work distribution.
e) Continuous quality analysis (profiles, trends, problems) and other properties, as well as possible detailed scheduling adjustments.

Production execution requires:

a) Monitoring the status of the process. For industries with complex processes, production control is vitally important. For example, metals applications contain multiple temperature and thickness controllers. In paper machines basis weight, moisture, and caliper are continuously measured and controlled in both machine and cross direction.
b) Early detection of potential problems and support of automatic data analysis.
c) Quality monitoring using various sensors (online and offline) for checking multiple quality properties. Samples are collected and analyzed by the laboratory.
d) Tracking, acquisition, and analysis of material, emissions, and energy consumption data.
e) Support of computer-aided planning and control systems by manual interaction.
f) Manual dispatching of process stages by operators when no integration platform exists.
g) Internal material transportation using cranes and forklifts.
h) Compilation of quality documentation for each customer order and preparation of all documents for delivery.

Production evaluation requires:

a) Automated quality control systems with highly sophisticated measurement technology (extreme temperatures, speeds, etc.) as well as correspondingly fast PIMS / LIMS.
b) Availability of material properties and documentation of specialties. These must be available immediately after production because quality documents are frequently part of deliveries.
c) Comparison of multiple quality properties with corresponding customer requirements and potential actions for rejection or further reprocessing of products.

Both paper and metal manufacturing are heavy production processes. For example, a paper machine running at a speed of 100 km / h with a paper width of 8 m and basis weight of 100 g / m^2 produces 80 tons of paper per hour (or about 1,3 t / min). Steel slabs usually weigh around 15-25 tons. Typical batch (heat) sizes range from 120 to 150 tons, and the typical throughput of a steel plant is 50 to 100 t / h. This results in an hourly product value of 40.000 to 200.000 Euro. Since the production processes in both industries are also very energy-intensive, a well running MES is vitally important.

5.7.2 Operations supported by MES Functions

Activities	Areas: Production	Areas: Quality	Areas: Maintenance	Areas: Inventory
Resource Management	**Material stock levels administration** • Link with related manufacturing chain (melt shop, rolling mill, processing lines, etc.), to assure problem-free flow of materials • Interface to Tracking: What is the current material level? • Complex MES and CPM systems (often comprising several solutions). Dealing with the interfaces between the applications is challenging • ATP (Available to Promise) and CTP (Capable to Promise) checks • Flexible adjustment to production personnel planning. For example, paper machines can only be attended by specially trained employees • Safety rules which must be constantly observed (vital for all heavy industry processes) **Personnel administration included in the scope of an ERP system**	**Administration of** • Test equipment and instruments	**Monitoring the state of production resources (asset management)** • Information about the performance of individual production units • Asset Management modules; providing information for state-oriented inspection and service (predictive maintenance) • Link to Execution Management and Data Collection: Monitor plant for operational failures and run diagnostics • Close coordination between maintenance, production and manufacturing planning	**Stock level control** • Reports on reconciliation and losses for product cost calculation • Manufacturing area considered as part of stocked goods capacity
Definition Management	**Administration of product information** • Manufacturing rules, recipes, Standard Operating Procedures (SOP), Standard Operating Conditions (SOC) • Use of product manufacturing rules (in metals manufacturing especially) • Collection of rules, frequently in databases; changes may only be made by authorized personnel (recipe administration)	**Quality specification and procedures for quality checking** • Test methods and procedures • Define product quality using a variety of customer-specific properties	**Administration** • Complying with special guidelines and service intervals, that also need to be respected by production	**Definition and administration** • Inventory and transport instructions for materials • Stock levels
Detailed Scheduling	**Generating detailed, realizable production plans** • Machine allocation and sequencing for production according to specifications • Waste / trim-loss optimization in the paper industry, also campaign planning for pulp & paper and metal production • Interface to ERP system for transferring process orders from ERP • Manual procedure for evaluating and adjusting optimized detailed production schedules - e.g. cutting plan changes, order grouping - shifting and processing customer orders • Advising on resource and material bottlenecks at the anticipated time	**Planning** • Necessary quality actions (analyses, tests etc.) • Required analyses	**Administration of maintenance orders** • Close integration of Maintenance and other service tasks with Detailed Scheduling, to avoid bottlenecks	**Administration of** • Intermediate inventory • Transport • Material release **Inventory level plays an important part in processes with multiple production steps: It must be clarified if an intermediate product is available or will have to be produced**
Dispatching	**Issuing work orders** • Dispatching work order at the plant floor based on the acceptance of a selected production plan • Final decisions regarding production plants and manufacturing stages • Manual correction actions as needed (short-term changes or non-automatic steps) • Coordinating the entire course of production	**Order assignment** • of test orders	**Issuing** • Planned maintenance work orders to the associated teams	**Order assignment** • Handover of orders for determining inventory levels • Administration of necessary transport operations
Execution Management	**Execution management / production tracking** • Status display of actual versus planned states with alarms at deviations • Manufacturing monitoring and control functions especially in industries with complex and fast processes, e.g. - Monitoring and control of pulp-mix and the dry end of the paper machine - Material breaks, a critical problem for rolling processes • Compliance with environmental and safety regulations • Material and energy requirements to carry out the production plan	**Carrying out quality checks** • Monitoring product characteristics / tolerances	**Monitoring and execution of maintenance orders** • Forwarding unexpected events to Detailed Scheduling	**Checking and monitoring** • Storage and transport procedures • Status reports • Storage level accounting
Data Collection	**Electronic data recording** • Transfer of LIMS and QCS analysis data and MES batch data into product documentation • Evaluation and transfer of sensor values and status information	**Quality monitoring** • Data processing (calculations, reports) and database administration • Transferring data to other MES components **The scope and complexity of these quality modules can vary significantly**	**Administration** • Maintenance history of the associated plant units / components • Condition of components in maintenance • Downtime • Resources needed (personnel, spare parts, time and expenses)	**Procurement and evaluation** • Inventory activities, levels and conditions • Necessary past expenditure concerning storage and transport
Tracking	**Tracking production targets and quality** • Analyzing time discrepancies • KPIs (material, energy, production costs, emissions)	**Gathering quality data** • Collecting quality-relevant discrepancies (time, values, equipment, key data) • Analysis and reporting of failures (historical databases)	**Tracking of planned and completed maintenance orders** • Preparing the maintenance processes via production analysis data • Checking the condition of devices for planned maintenance orders	**Collecting storage utilization** • Storage location, products, transportation processes • Registration of RFID and barcodes for future tracing
Analysis	**Production analysis** • Production plant cycle times (statistical values are used in production planning) • Utilization, performance and process efficiency • Calculation of Key Performance Indicators (KPIs)	**Quality monitoring, evaluation and documentation of** • Quality-related discrepancies • Pulp & paper: online QCS (Quality Control Systems) measurement devices, visual analysis WIS (Web Imaging Systems) and laboratory tests • Metals: analysis of slab quality (surface), chemical composition	**Determining** • Optimal maintenance strategy • Return on Assets (ROA) • Maintenance indicators for further optimization	**Administration of** • Inventory analysis regarding storage efficiency and resource utilization • Overview of delivery quality, storage losses and material movements • Determining inventory indicators

Table 8: MES modules for paper and metal production according to the process model

6 Essential similarities and differences between MES applications in the process and manufacturing industries

Today's high-performance operations management concepts must handle ever more varied requirements, and be able to respond flexibly to a multitude of challenges. These include fast changing customer demands and procurement markets.

These kinds of changes can directly influence day-to-day production planning at short notice as well as control of the associated production orders. In the process industry, start-up and shut-down procedures, and product and load changes are more frequent than in the past. In the manufacturing industry, shrinking lot sizes are accompanied by an increasing number of product switchovers and a higher number of product variants.

For both industries, mastering these challenges is a basic requirement for increasing the own competitiveness and succeeding in the global marketplace.

Both industries implement a multitude of specialized solutions for their respective specific problems. However, in addition to basic MES tasks which are inherently comparable, there are many structural analogies which can lead to common solution concepts. Mutual appreciation of the respective similarities and differences will assist in the implementation of such solutions and help in breaking down barriers between the industries. Hybrid production facilities in particular will benefit directly from this approach.

The following chapter presents the immediately visible similarities and structural analogies between both industries. The chapter after that highlights the distinguishing characteristics.

6.1 Similarities

Both the process and manufacturing industries are impeded from common and considerable shortcomings in the coordination of adjacent business processes. This restricts consistent and enterprise-wide flow of information, and thus limits dynamic and efficient operations management.

Almost all industries still share the same information barriers:
- MES applications are not sufficiently networked within the plant environment. This results in insufficient availability of data for decision support and control of operations.
- Information is not sufficiently up to date.
- Organizational inconsistencies between the higher level ERP system and MES applications due to different data structures and varying level of information detail.
- Lack of suitable tools to close the informational gaps in the control mechanisms which are required for market-oriented manufacturing.

Even though the manufacturing organizations in both industries have different characteristics, they share a number of common economic goals:
- Efficient utilization of raw materials and energy
- Minimization of production outages
- Improving plant utilization
- Managing a wide range of products
- Consistently high product quality.

For all market segments and industries, MES must provide vertical and horizontal integration in real time and in synchronization with adjacent systems. With these requirements, it is equally important for both the process and the manufacturing industries that MES applications support planning and monitoring as well as communication tasks for the efficient organization and execution of production orders.

In continuous manufacturing, production mostly operates batch or semi-batch processes. Batch operations in the process industry can be considered equivalent to the production of discrete parts. The plant often consists of networked manufacturing areas which can also run independently of each other. This corresponds to the standalone production areas in the manufacturing industry. The level of interaction between these production areas depends on the product being manufactured. For all cases, the flow of products in and between the respective areas must be coordinated and synchronized.

Process control systems with integrated batch control capabilities manage the corresponding manufacturing processes using so-called master and control recipes. These recipes define the production procedures and production parameters needed to convert the raw materials into products. In addition, the recipe definitions ensure that the production process is executed within the specified tolerances.

Recipes can also be managed and executed on the control system level (DCS). If such "intelligent" subsystems are integrated in the MES environment, the executing intelligence shifts from the MES application to the equipment control level.

The advantage of this kind of distributed intelligence is a certain independence of the MES application. In case of an MES failure, the production in the associated production units can continue.

The manufacturing industry has a corresponding equivalent. In highly automated, flexible robot-controlled assembly lines, the various programs for the conveyor, handling, assembly, or welding processes are managed in a product-oriented manner by the robot controllers.

In batch processes, documentation usually includes only the specific charts which have been generated during the production of a batch. These would typically be included in the batch report. The conversion of continuous records into time-discrete representations associated with a specific batch is a requirement for MES applications in the process industry. This functionality requires an interface with the recipe module of the DCS which allows the correlation of batch events and the corresponding trend data.

This kind of interface enables seamless logging of manufacturing data as well has batch tracking for a product. System interventions as well as changes to work flow, recipes, and batch reports are documented in a comprehensive, reproducible, and tamper-proof manner.

In pharmaceutical plants, this function is mandatory as per FDA regulation 21 CFR Part 11 [5], [6]. This function is also required in less stringent form for the food and beverage industry.

Product Lifecycle Management (PLM) is the manufacturing industry's equivalent. These systems collect the data for safety-relevant components and trace them far beyond the actual production, for example airbags, brakes, and motor controllers. Tracing across production boundaries requires that a component's most important data are associated with a unique serial number or at least a batch number. During the assembly process, this component is integrated in larger components and eventually in the final product. The component's data are included in the product record. Production guidelines and regulations have to be taken into account.

Both the process and manufacturing industries are facing the continued challenge of engineering and design integration between the involved automation levels which hinges on the "single point of information" principle.

6.2 Differences

In general, the major difference between the two industries is the considerably greater diversity of products and product variants in the manufacturing industry.

This results in specific requirements for MES applications, especially for production scheduling and controlling of production orders and partial orders. In the manufacturing industry, intermediate and final products generally consist of a high number of individual components. In addition, this industry's production process is characterized by highly interconnected equipment with little buffer storage. Therefore, MES applications are often used for controlling interconnected production steps in the manufacturing industry.

These manufacturing industry characteristics require effective management of a demanding supply chain. The requirements on MES applications for data update, completeness, consistency, volume, and processing speed are higher than in the process industry.

Manufacturing plants frequently employ equipment from different vendors which often implement heterogeneous data processing and MES solutions. Comprehensive and integrated control systems are less common in the manufacturing industry than in the process industry.

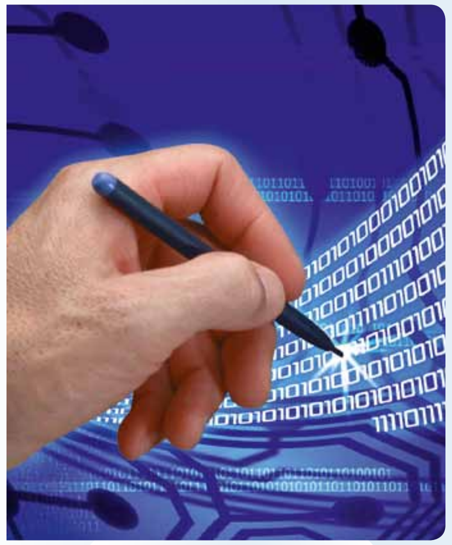
In general, the bills of materials and manufacturing plans common in discrete manufacturing are much less suited for describing and modeling the prevalent work processes of the process industry.

On the other hand, MES applications in the process industry must be capable to collect the recipe structure and parameters from the connected systems both as master data and dynamic data for the control and documentation of production orders, and store them in appropriate database structures.

Unlike discrete manufacturing which uses the ERP system, the process industry defines the production instructions (i.e. master recipes) in the MES or DCS recipe module. The master recipes are subject to stringent test and validation procedures before they can be used for production. The latter aspects are particularly important for the pharmaceutical and food and beverage industries for guaranteeing product safety.

In the process industry, most measurements are continuously collected and archived in the form of plots or trends. The archive time spans are generally measured in years. Since the measured values and the resulting plots can change quickly, the archives must be designed accordingly. In this environment, standard SQL databases are generally less suitable due to their limited performance. Instead, special database are used which support processing large volumes of fast changing measured values and use special algorithms for compression and reduction of collected data.

7 Practical advice for approaching MES projects



This chapter presents a number of tips and recommendations which have proven themselves in practice during the implementation of MES. It contains suggestions and ideas and does not replace established software project implementation procedures.

Manufacturing Execution Systems are basically IT tools which when properly implemented and introduced, contribute to the efficient and comprehensive solution of production issues. Like all other IT tools, MES tools "per se" do not solve problems. Instead, problems and difficult tasks must be thoroughly analyzed and solved based on actual requirements, and the results be recorded in functional design specification in order to subsequently implement IT tools.

In the following, sample objectives for producing enterprises are presented. Even a subset of these objectives supply ample reasons for introducing MES.

Examples for objectives
A selection of typical objectives which justify the implementation of MES are summarized below ([2], appendix B). The relevance of these requirements varies heavily between industries.

- Availability / capable to promise:
  Ability to determine short-term delivery dates and quantities from inventory levels, manufacturing capacity, and raw material stocks and deliveries.
- Cycle time reduction:
  Use of available information and optimization strategies to organize production and solve interruptions in such a way that the time between order receipt and delivery is minimized, and thus return of assets (ROA) is maximized.
- Production efficiency / production cost savings:
  Lower production costs by reducing resources (materials, raw materials, energy and personnel) without quality losses.
- Asset efficiency:
  Increase of return of assets (ROA) resulting from maximization of plant utilization and minimization of plant costs. This is accomplished by assembling and preparing available information for use in production optimization strategies and improved fault responses.
- Agile manufacturing:
  Flexible and time-sequence optimized operation of manufacturing plants in order to maximize production using the existing facilities.
- Supply chain optimization:
  Organization of delivery of raw materials and components from suppliers so that they are available at minimized cost and in time for production.
- Quality and traceability:
  Preparation of available information for quality verification of raw materials, supplied parts, and products, for tracking of usage, and for ensuring compliance with government and other regulations.
- Operator empowerment:
  Delegation of decision-making responsibility to production-level employees. This requires availability of decision support information used on higher corporate levels to production personnel.
- Improved planning:
  Improvement of production scheduling is a permanent objective of all enterprises. It requires continuous feedback concerning production, utilized resources, and current stock levels.
- Inventory reduction:
  Minimizing inventory is a key factor in increasing competitiveness and requires process adjustments in logistics, inventory management, and production as well as reduction of throughput times. At the same time, supply of materials must be optimized, for example by supplier-controlled stock level management, or internally by using demand-optimized stocking with a real time view of production and finished product storage capacities.

MES: internetworking projects

MES solutions are characterized by a high degree of internetworking within a company, and therefore have to be considered as (complex) systems. The initiators of such a project usually belong to the management level. They must empower the planners and implementers of MES solutions to act across department boundaries and involve any area of the enterprise as needed.

All affected areas of an enterprise must be obligated to support the MES implementation.

If possible, the MES introduction should be limited, i.e. only one or a few areas within the enterprise carry the burden of the initial implementation. Afterwards, MES is rolled out to the remaining corporate areas.

Waiting for the full completion of the introduction carries the risk of significantly prolonging the roll-out. Instead, once a certain scope of functions has been implemented, the subsequent stages must be initiated. This requires a certain amount of courage.

MES support operational processes which are subject to continual changes, for example due to ongoing Continuous Improvement Processes. Thus, its completion can often not be precisely determined. At this point, moving forward will be rewarded by an earlier increase of ROI.

MES-related aspects for analysis of current status and definitions of requirements

The introduction of MES follows the same procedures as other large software projects, and established methodologies can be applied. However, in practice the standard approach consisting of

- Analysis of current status and existing processes,
- User Requirement Specification,
- Definition of objectives,
- Request for proposal,
- Vendor selection,
- Functional specification,
- Implementation

is managed more pragmatically, especially by medium-sized enterprises. Budget planners generally have overall insight whether the project should be implemented as a turn-key solution, or use the best-of-class solutions available on the market. The latter choice requires significant technical and organizational efforts by the implementing corporation.

This is also an opportunity to change old habits and to design processes in the light of modern aspects which frequently represent a standard or de-facto standard. At the same time, MES products must be connected with existing IT and automation environments. New products being installed need to be technically compatible with existing systems and use open architecture in order to facilitate future extensions using products from other vendors.

The following list of successive steps shows which aspects must be considered.

Description, analysis, and documentation of relevant and current processes:

- Process flow: all interactions in existing business processes must be collected and described. Any variations in a specific business process must be included accordingly.
- Documentation: the respective documents (both paper and electronic) such as work descriptions, parts lists, feedback forms etc. must be assigned to each business process. In addition, the process data acquisition must be documented.
- Involved systems: for each business process, the interaction with associated IT and automation components (PCs, scanners, PLCs, DCS, batch control system, master station, ERP system, etc.) must be assigned.
- Infrastructure: the existing and required energy and communications infrastructure (network, terminals, handhelds, etc.) must be reviewed.

Then the target processes are defined based on the description and analysis of the current processes and the technical and organizational corporate constraints:

- Standardization: the definition of target processes should include the company-wide standardization of comparable processes or introduction of generally accepted standards.
- Best Practices: the documented processes must be checked against proven methods as well as existing standards and adapted as needed.
- Automation: optimization of target processes with regard to online data acquisition, consistency, reliability, and availability of information.

Based on the defined target processes, the evaluation matrix for the request for proposal can be created. General as well as enterprise-specific standards must be included. The evaluation matrix may include the following points:

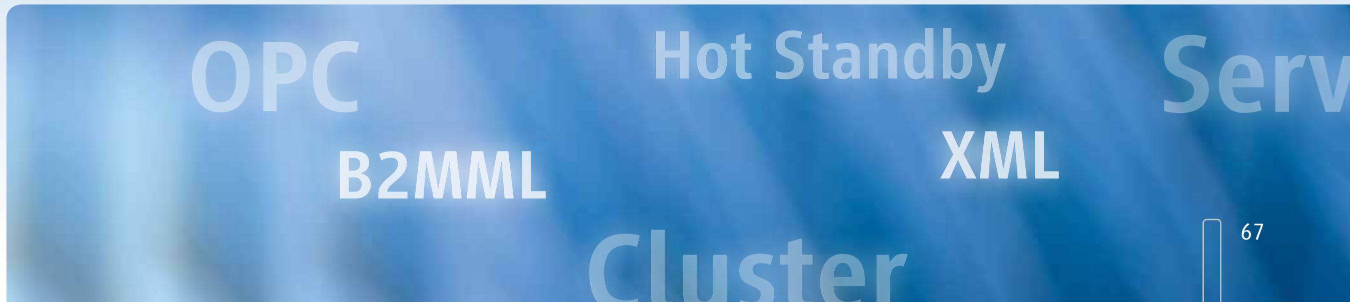
- List of functions to be implemented
- Integration platform (standards like OPC, XML, B2MML etc.)
- Software platforms (operating system, database system, development environment etc.)
- Hardware concept (single server, cold / hot standby, cluster etc.)
- Roll-out concept
- Time schedule
- System availability
- Service and support
- MES product roadmap (updates and upgrades)
- Prices (hardware, software, services, maintenance, etc.)
- References.

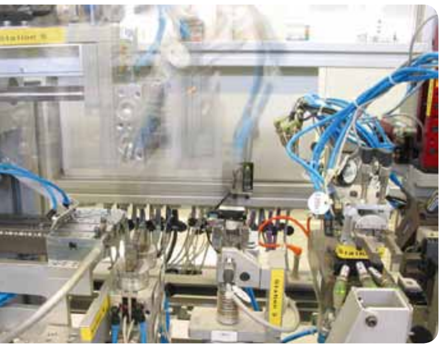
The listed points and criteria provide only a general guideline which must be adapted and extended for each specific project.

Selecting a vendor

Vendor selection should be approached systematically, even if vendors have been preselected due to budget reasons. It is recommended use standard approaches, for example IEC 62264, to structure this complex task. The level model described in IEC 62264 classifies and assigns the systems which are to be connected, from the automation level to the ERP level.

The identified or specified functional scope can be classified based on the functional model listed in the standard, as well as checked and expanded for completeness, connection to adjacent systems or functional complexes, required data flow, etc. This approach has the advantage that the basics for the functional design specification do not have to be first defined project-specifically. The result is a vendor-neutral document for vendor selection which is based on established standards. At the same time, the vendor is in a position to evaluate the functional model and submit an offer which is structured accordingly. Finally, the subsequent evaluation is simplified by structurally comparable offers.





The selection of an MES generally also results in a long-term relationship with the vendor and is a major factor of protection of the investment. In addition, training costs for users and administrators must be considered part of the project implementation. The vendor must be able to release new versions of the system when underlying factors such as database or operating systems have changed. Due to the short innovation cycles of hardware components and IT solutions, unlimited continuation of the status quo after successful introduction of the system is prohibitively expensive. Changes in the MES environment require adequate responses. MES usually have multiple interfaces to ERP, DCS, PLC, and other systems. The vendor must be able to guarantee long term (up to 15 years) maintenance and further development of his MES products, and must systematically incorporate customer requirements in product development.

Therefore, investment analysis has to consider the projected total life cycle of the system including all related subsequent expenses in terms of Total Cost of Ownership (TCO).

System engineering requirements
The following aspects beyond the actual MES performance should be considered during the system selection.

- Availability:
  The availability requirements determine the necessary technical and organizational steps, such redundancy or buffer mechanisms. 24/7 availability may be an overreaching stipulation. The system must be able to support the availability requirements. Organizational considerations such as backup and archiving during ongoing operations must also be taken into account.
- Openness and compatibility:
  In most cases, MES products must be integrated with existing corporate IT and automation systems. The products to be installed must be technically compatible with the existing systems and use open interfaces in order to allow future extensions using products from other vendors.
- Operational and support requirements:
  It must be possible to recognize and resolve failures quickly. The system must be self-monitoring and automatically log all messages to enable timely analysis. For more detailed investigation, monitoring and debugging features must be available. After system failure, restarting the system and restoration of connections to adjacent systems should occur automatically whenever possible.

  The system needs to support backup and restoration of data in order to allow fast system restoration after a failure.

  Changes to master data, such as user accounts, manufacturing instructions (recipes), or material master data must be possible without interrupting normal system operations.

Regulatory Compliance
For most industries, recording of production data and assigning of the data to products is required by law, government authorities, or manufacturing associations. The food and beverage, pharmaceutical, and cosmetics industries are obviously subject, but also any manufacturer of products which affect human health and safety, for example automotive or electrical enterprises. Environmental aspects are also increasingly legislated.

The pharmaceutical industry is subject to the requirements specified in GMP or EU 178. Typical aspects are the protection of archived data against modifications and tampering, and maintenance of the data in readable and presentable format for at least ten years. Requirements regarding testing records and electronic signatures are also included in the scope.

8 Added value and benefits

MES modules have been in operational use for more than two decades. It could be expected that the benefit of these applications had been widely accepted and the added value been proven and documented by the multitude of completed projects. In reality, the economic benefits are continuously evaluated and reexamined in every new project. The reasons are the multi-disciplinary and complex correlations as well as the difficulty defining a generally applicable method of quantifying the benefits.

The question of the added value and benefits of MES has a seemingly simple, yet more quality-related answer. The benefits are the improved efficiency of the corporate organization and its processes. Factors such as accuracy and timely availability of operational data, increased throughput, cost reduction, and customer satisfaction are primary accomplishments.

Thus, MES solutions are a key factor in an enterprise's pursuit of operational excellence, and are closely related to analysis and optimization of operational processes.

The following areas show the optimization potential associated with introduction of MES:

- Increased transparency of inventory and production capacity and thus
  - Online access to possible delivery dates at order entry,
  - Improved analysis with regard to requested delivery dates and total delivery costs,
  - Faster planning and order fulfillment,
  - Increased delivery reliability,
  - Higher flexibility in response to changes,
  - More efficient plant utilization.
- Reduction of errors and defects by permanent computer-based monitoring of all important production parameters.
- Reduction of production costs and better utilization of plant capacity as a result of computer-based production planning and scheduling.
- Reduction of set-up times by optimization of plant allocation.
- Inventory reduction (raw materials, finished products) by improved planning, and more flexible and demand-oriented production.
- More effective procedures by networking and comprehensive data exchange between involved operational and automation levels (ERP, MES, DCS).
- Effective organization, monitoring, and documentation of processes which are subject to regulatory compliance (e.g. cGMP / FDA).
- Faster data analysis and release of production batches resulting in lower finished product inventory.

8 ADDED VALUE AND BENEFITS

Of course, an actual benefit analysis applies only to a specific instance since the individual requirements and scope of tasks do not allow a generic analysis.

The quantitative aspects of an MES project's benefit are determined solely by a precise comparison of the procedures and the related costs before and after the introduction of the system. Effects outside the actual operational processes, such as more reliable delivery scheduling, avoidance of contractual penalties, and reduction of personnel interruptions must be included as well.

Therefore, a target/current state analysis including a description of the current and future processes is recommended as part of project preparation and for evaluation of the anticipated benefits. This study also presents the greatest potential and the resulting areas of activity in a step-by-step MES introduction. The interactions between modules generate particularly positive effects when the modules are designed as integrated elements in a comprehensive automation solution. The relevance of individual modules depends on specific plants and industries. Assuming an MES investment of 1% (for large continuous plants) to 10% (e.g. pharmaceutical plants) of the total project cost, ROI is typically accomplished in one to two years. Additional but difficult to calculate MES benefits (soft earnings) further shorten the ROI period.

Figure 16 graphically illustrates the statements of production plants regarding the observed potentials.

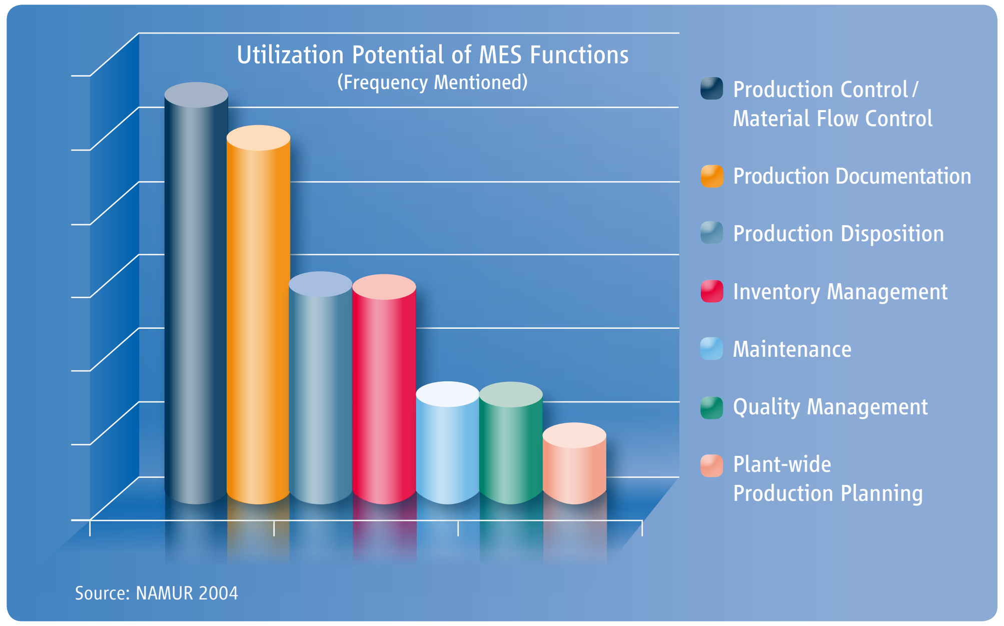


Figure 16: MES potential

Implementation reports in relevant technical publications describe the benefits of implemented MES solutions, including steps for accomplishing the objectives, as well as additional planned and unforeseen effects.

The purpose of this brochure is the consideration and evaluation of MES across industries. Therefore, case studies from already completed projects are presented as well. Even though the comparability of accomplished results is to some degree diminished, different aspects have been emphasized on purpose in order to accentuate the diversity of attainable goals.

Each case study describes the plant or process, the initial situation before the introduction of MES, the implemented MES solution, the achieved benefits, and additional project-specific characteristics. When possible, the results were quantified, and the provided absolute values should be considered attainable examples.

8.1 Biopharma case study: comprehensive plant automation – ERP-MES-DCS

Process description

This study presents a biotechnological plant for the production of active biopharmaceutical ingredients as an example of comprehensive automation across multiple automation levels. The typical stages of the production process consist of media preparation, media addition, reactor sterilization, inoculation, fermentation, harvesting, product transfer, and cleaning. Two preparation lines and eight fermenters represent the core of the plant. A total of 80 process units have been integrated in the overall concept, including cleaning units (WFI, purified steam, cleaning in place), chromatography, and filtration.

Initial situation

The operational processes and production decisions in the newly constructed active ingredient plant were to be supported by MES software already available on the market. Early on it became apparent that MES modules generally operate as standalone applications and can only communicate and exchange data with adjacent automation levels, especially control system functions, using specific interfaces. This often results in a variety of approaches and implementations offering insufficient interoperability and inconsistent operator environments.

MES solution

Readily available control technology and MES software were chosen for the management and control of the plant. The concept implemented both parts as an integrated environment across all automation levels while fulfilling regulatory requirements. This applies to project engineering, the recipe-controlled procedures, and operator handling. Recipes are defined and administered centrally including version management. During execution, control is transferred as necessary to other more suitable systems for specialized sub-tasks. The concept also includes mobile reaction units, electronically generated manufacturing instructions for manual procedures, integrated material tracking, optimized utilization of operational assets (equipment, material, personnel), interfacing with quality data from the laboratory, the scheduling of products, and integration with business-oriented enterprise software. The system comprises a total of 50 networked computers with server functionality, 60 process controllers, 20 PLCs and more than 100 operator stations.

The automatic creation and release of regulatory compliant batch reports is an additional feature of this implementation.

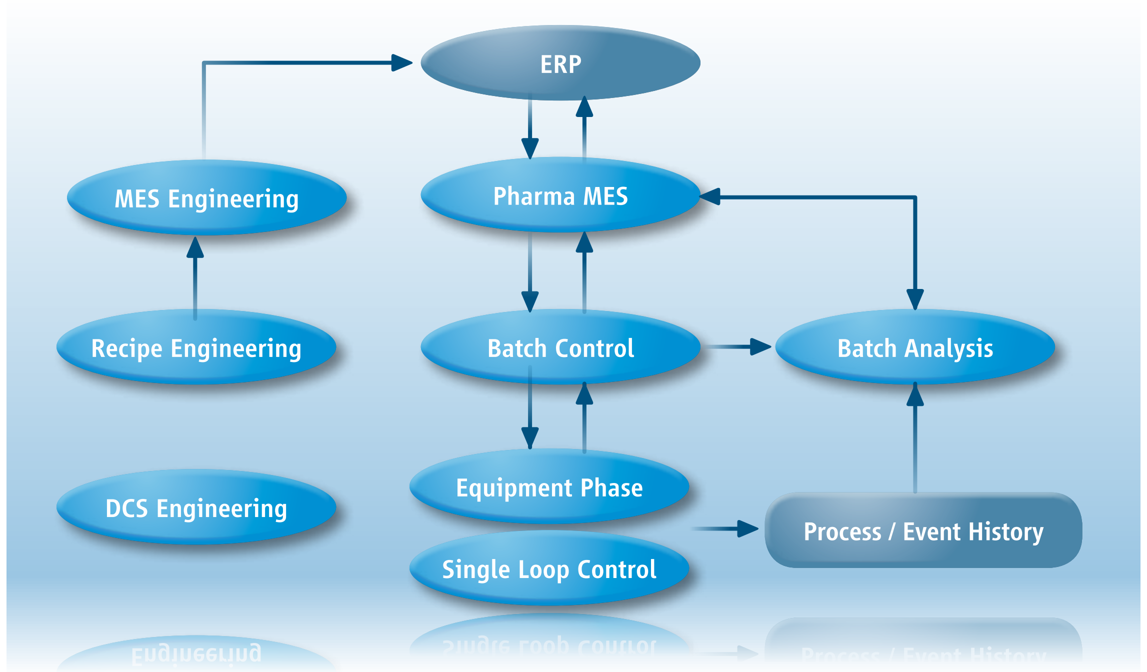


Figure 17: Integrated automation concept

Added value and benefits

The installed computer-based solution replaces the paper-based documentation and significantly reduces the previous time-consuming procedures for product release. The time required for collection, verification, data editing, and release approval was reduced from several weeks to a few hours. The results are quantifiable and significant.

Risks and costs in all application phases were minimized by the comprehensive concept with its uniform operator environment and interdisciplinary implementation. Project engineering, operations, and quality assurance are sharing a standardized system for accessing and displaying all available production data. Departments previously operating independently now work hand in hand as one unit based on a jointly defined direction which has resulted in savings of more than 30%.

The overall economic benefit of the integrated solution and the computer-based reporting system exceeds 2 million Euro per year. This figure does not reflect the qualitative results such as improved corporate communications, the benefits of a more efficient project phase, and the improved analysis and procedural optimization based on the central information base.

Further information

The entire project was completed in approximately 2 years.

8.2 Food and beverage case study: energy data acquisition as decision support for investments

Process description

A major manufacturer of mineral water and soft drinks fills a total of 200 million bottles per year at one of its plants. The production facilities basically consist of the water supply, the syrup unit, subsequent mixing of the drinks, and the bottling plant for reusable bottles.

An auxiliary area provides hot water and steam for production as well as heating and cleaning of the facilities.

Initial situation

Energy bottlenecks, especially on cold winter days, required an upgrade investment for heating system. The existing boiler with a steam output of 6 t / h which was installed in 1978 had to be replaced.

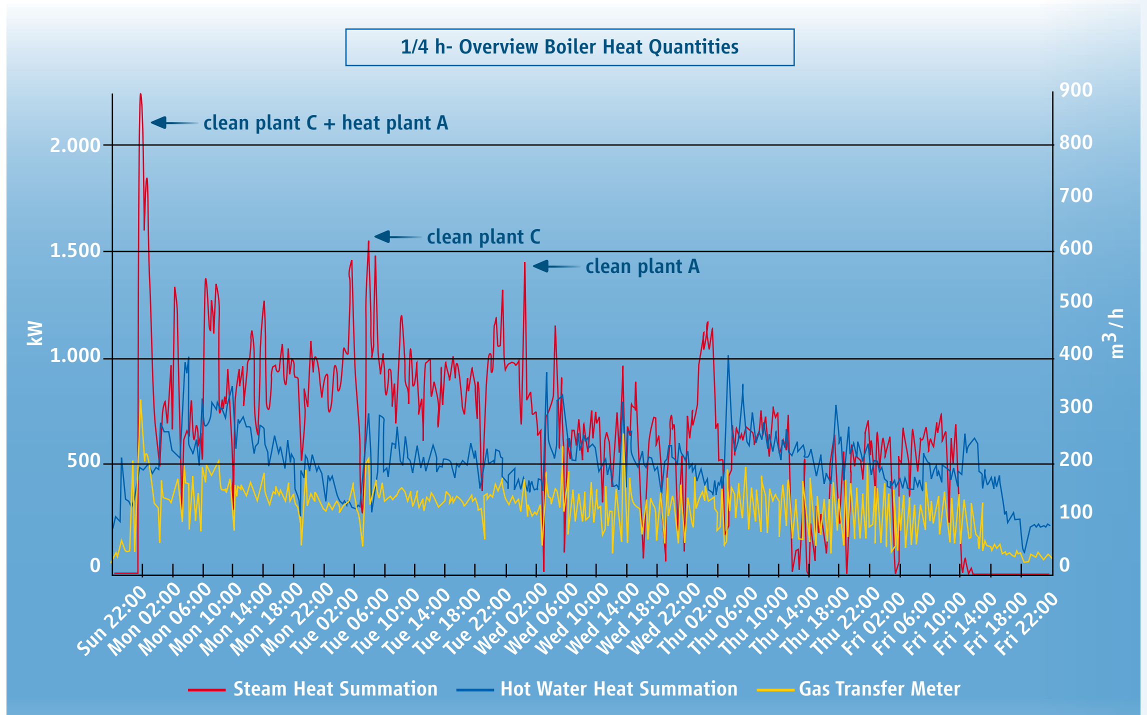
Sizing the new boiler proved to be the main challenge in this case. The only basis for the size estimate was the maximum utilization which was available only as monthly data. This basis was insufficient for exact calculation of the hot water and steam demand.

In addition, the energy distribution within the plant was unknown since the consumption of individual units was not available.

MES solution

An energy management system was installed in order to determine the demand and to provide reliable decision support. In addition to measuring the consumption of gas and electricity (primary energy), the system also collects demand data for hot water and steam (secondary energy) and controls shutoffs during peak load.

Heat meters were installed in the boiler house to determine the amount of energy consumed by hot water. Steam flow meters, gas meters for measuring individual gas boiler consumption, and electricity meters at transformer outputs and individual units were installed as well. All meters were connected to an existing bus system and integrated into the energy management system. Six months later enough data had been collected for the investment decision. The evaluation showed that a smaller steam boiler with an output of 4 t / h would be sufficient. The existing hot water boiler with a capacity of 2.400 kW would absorb the heating demand peaks during winter months, and the old boiler would be retained as backup.



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	Energy	Peak	Gas Consumption
Total	144.560 kWh	2.792 kW	15.831 m³
Steam Heat Summation	79.907 kWh	2.292 kW	7.525 m³
Hot Water Heat Summation	69.632 kWh	1.040 kW	8.306 m³
High-Speed Steam Gen.	- kWh	- kW	0 m³

Figure 18: Heat quantities overview

Added value and benefits

The data provided by the energy management system showed the precise amount of energy required for manufacture of specific products on specific production units. This allowed targeted optimization of production processes (figure 18). Individual units are no longer started up simultaneously in order to avoid load peaks. Peak load management monitors and controls plant ventilation, office and control room air conditioning, and waste water treatment. The objective is the long-term reduction of the plant's electricity demand peaks and gas supply reserves. Load peaks are planned to be reduced from 1.850 kW to 1.700 kW, resulting in annual savings of about 10.000 Euro. Reducing the gas supply reserves from 4.000 kWh to 3.000 kWh will save an additional 7.000 Euro per year.

8.3 Refinery case study: long term planning and scheduling

Process description

The analyzed refinery has a capacity of 125.000 bpd. In addition to crude oil processing, the company also markets primary oil products and provides application support to its customers. The company operates a lubricant blending facility on the same site.

The refinery produces unleaded gas oil, lubricants and other chemicals. Due changes in demand for unleaded gas oils, production of higher octane products was increased.

Initial situation

To a great extent, existing planning tools managed the established purchasing channels and product variants of the refinery. The product line change required by the unleaded gasoline market called for new systems and modeling tools for flexible and timely material planning. The emphasis was on transparent handling in order to enable company personnel to manage and maintain the system, and minimize involvement of external modeling and system specialists. The phased introduction of the new installation had to reuse the infrastructure of the existing system, and the internal work flow and the tank data administration needed to be improved.

8 ADDED VALUE AND BENEFITS

MES solution

The implemented model-based solution analyzes feasibility and economics of alternative product strategies, and performs the monthly planning for the refinery supply. The first module handles the phased plant transition. The initial phase is the sulfur reduction in gasoline and diesel, followed by the shift to unleaded gasoline. The complex effects of the refinery modifications as well as the impact of new process units have been made transparent. This transparency provides decision support for the new focus.

Monthly planning is implemented in the second module which manages the supply chain including the selection and distribution of raw materials. It also sets targets for optimized production and product management for specific market sectors, and manages inventory levels and product distribution. The cross-department planning data are used in the refinery's LP model for determining schedules and blending as well as calculating APC application parameters.

A plant-wide data information system provides current process data, for example for updating the model values.

Added value and benefits

The model provides flexible analysis of parameters which affect the plant operation and the result of the refinery. The comprehensive decision support for strategic and economic planning and the realistic planning objectives contribute substantially to the bottom line. However, the exact economic effects can only be quantified based on assumptions. Bad strategic decisions due to missing basic data or poor planning flexibility regarding raw material procurement alternatives result in significant economic losses. The estimated savings in terms of cost of raw material are approximately 5% which translates to about 3 million Euro annually.

Additional benefits are optimized utilization of the blending units and simplified, computer-based work flows due to precise and contemporaneous input data. The simplified handling of the more transparent model structures provides additional financial advantages. Training and support for the data content are significantly more cost-effective than with the previous solution.

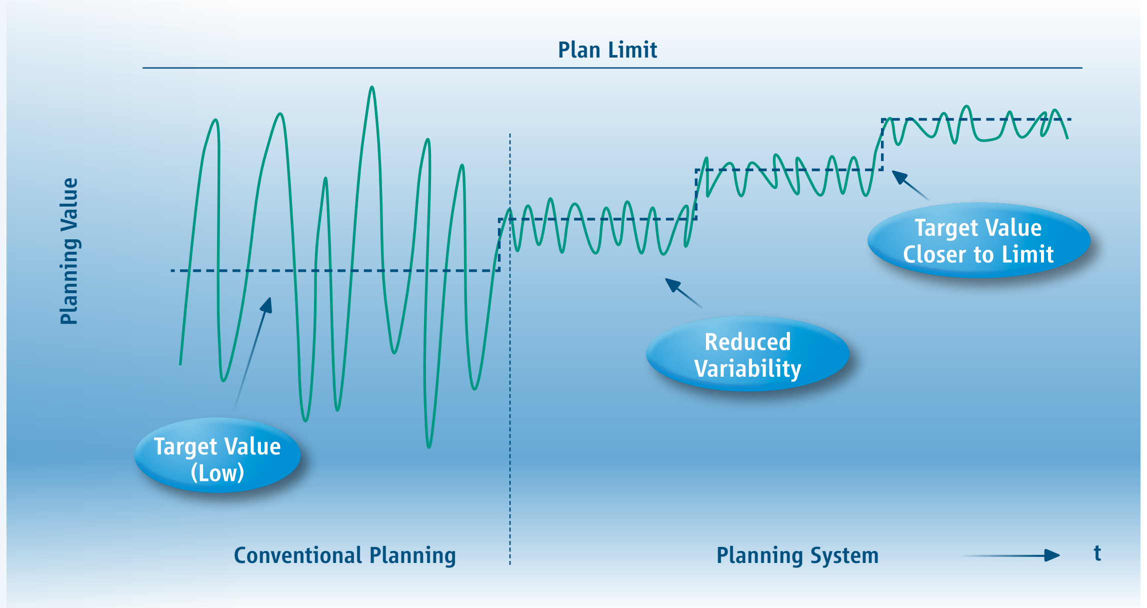


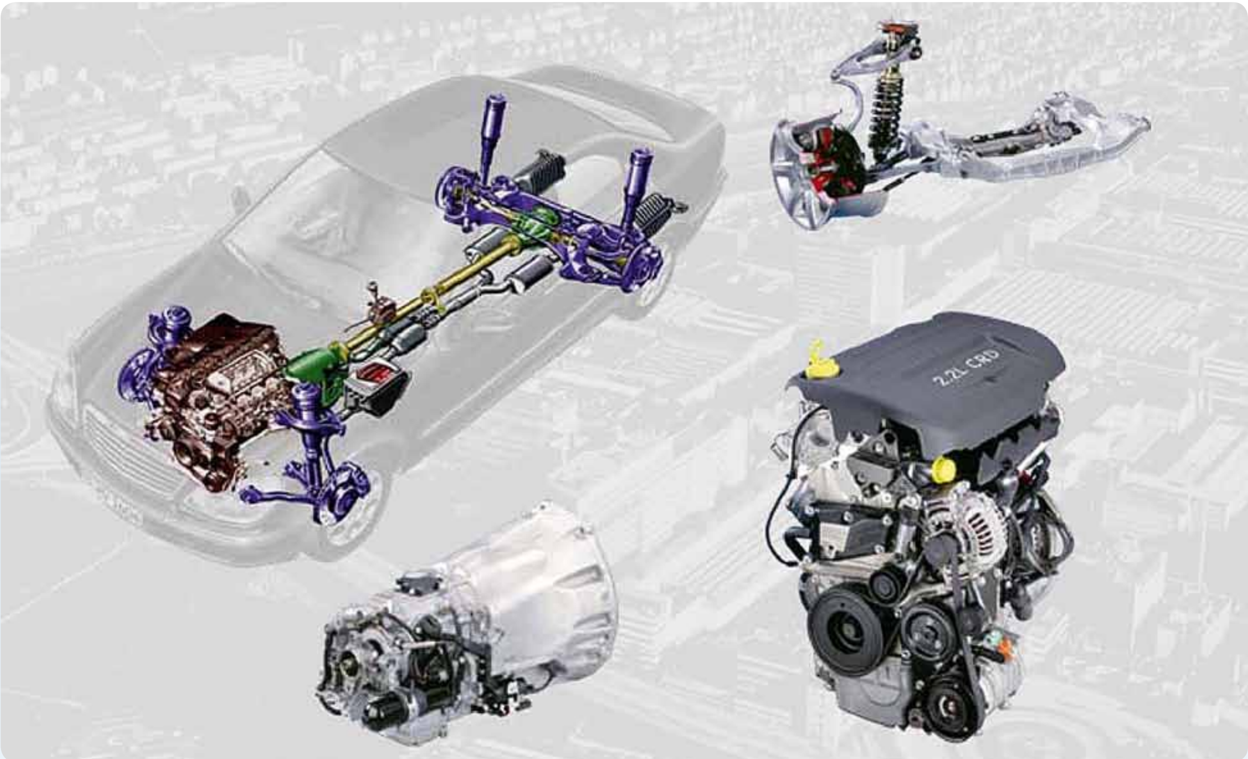
Figure 19: Effects of model-based planning

8.4 Automotive industry case study: order management for powertrain assembly

Process description
The situation in the automotive market is characterized by an increasing number of variants, reduced delivery schedules and the expectation of customers to be able to change their orders at short notice. Thus, the automotive industry must at the same time manage the increasing complexity, and respond more flexibly to customer demands and possible supply bottlenecks. The technical prerequisite is a comprehensive data flow from order entry to delivery and from ERP to machine control. A leading German automobile manufacturer decided to invest in the enterprise's future by implementing standard MES software for production sequence planning of powertrain assembly.

First tier suppliers, which include OEM-owned suppliers, deliver their systems or assemblies just-in-time or increasingly just-in-sequence directly to the assembly line of the automobile manufacturer. Stringent requirements for quality and delivery integrity must be fulfilled. Any failure in this area results in assembly line stoppage which must be avoided under all circumstances. The vertical range of manufacture for the power train is relatively high. Multiple variants increase the efforts required for automation, especially in combination with widely varying lot sizes.

Initial situation
In order to satisfy the requirements of assembly plants as internal customers, maximize plant utilization and achieve even production loads, production sequencing must be minutely planned, optimized and possibly readjusted. Previously, a proprietary production control system for managing the powertrain assembly had been used in all German plants. ERP orders were converted by the software into technical production orders for the assembly lines. Discontinuation of the installed hardware and software meant that future operation of the system was no longer ensured. Expansions as well as implementation of changed requirements had become impossible or too expensive. Therefore, the old system had to be replaced. Flexibility and future security of the proposed system were major considerations in awarding the contract for the implementation. The company's management soon decided on a standard MES system instead of an individually tailored implementation.



MES solution
The company selected an MES software framework which supports modular adaptation to specific requirements. The functional and technical standardization requirements and the roll-out flexibility required by different plants and equipment could only be satisfied by a flexible and adaptable MES solution.

In powertrain assembly, production orders coming from the ERP system must be enhanced with technical information to enable accurate production. The technical information consists of product specifications and specifications of the available line segments. This information is used to determine rules and structures for technical orders as well as line segments which are available for order processing. At execution time, the software computes the actual technical order based on the created rules and the production order. The technical order is loaded into the assembly station and stored on the respective unit (transmission, engine, axle, etc.) by the automation system. When a unit arrives at another assembly station, the station reads this information in order to execute the correct operation. At the same time, the MES collects the data in order to reproduce the processing steps. The production order status is fed back to the ERP system in real time.

The challenging system requirements regarding data volume and throughput, response times, and system availability were the focus of the project. Functions such as sequence planning, delivery capability controlling, product tracking, and production reporting were also implemented.

Added value and benefits
- The system's flexibility ensures optimum equipment utilization:

If material shortages prevent an assembly station from executing the planned orders, the MES suggests sequence changes which do not impact the specified scheduling. In case that the technical order backlog has been cleared, new technical orders can be requested directly from the respective line segment. This ensures that only orders relevant to the line segment are available.

The project data specifications reveal the complexity of the task. The system manages and executes technical production orders for 38 production lines and 5 shipping systems. During a period of 3 days up to 90.000 orders are simultaneously active, and 2 million orders are available online for a period of 3 months. Only data older than 3 months are archived. An order contains an average of 500 and a maximum of 2.000 attributes. 300 users can access the web-based solution simultaneously. Interfaces to 14 IT systems needed to be implemented.

- High-availability hardware architecture for operational security:

A highly sophisticated hardware architecture concept ensures 99,75 % availability. The central control system servers are clustered and networked with external storage systems. Distributed PC-based cell systems buffer the orders at shop-floor level and provide the capability to bridge outages for up to one hour. The capability of running assembly lines in standalone mode not only prevents downtimes due to system outages, but is also used for maintenance of the complete system.

In spite of a tight timeframe for the implementation of the new system, plant availability was never compromised. No disturbances affecting production have occurred.

- Improved economics by roll-out to additional plants:

2008 saw the start up of the assembly of a completely new engine type, and in 2009 the roll-out to other areas was begun. In the meantime, the system has proven itself by manufacturing order generation for V-type engines as well as smaller engine types. The roll-out for the production of front and back axles, transmissions and gasoline in-line engines is being prepared. Project completion is scheduled for 2011. The customer's project manager states that „the ability to adapt a software solution optimized for our needs to totally different assembly lines by means of simple parameter changes was really important to us. Having seen the trouble-free roll-out within engine manufacturing, we don't foresee any difficulty in expanding the system to axle and transmission assembly. The multiplication effect without the need for a new project provides enormous savings potential. The flexibility of the system is convincing even where adjustments for product changes in the IT environment are concerned".

The reduction of IT platforms to two levels and the standardization of the cell systems have resulted in a cost-effective and scalable hardware architecture.

- Investment for the future:

A future-proof standard product is only one of the factors required for vendor selection by the customer's project manager. Innovative technology per se does not guarantee a secure future, but must be combined with the vendor's capability to provide long-term product maintenance and upgrade paths. Both factors are required for customers to benefit from vendor innovations without major new implementations or adaptations.

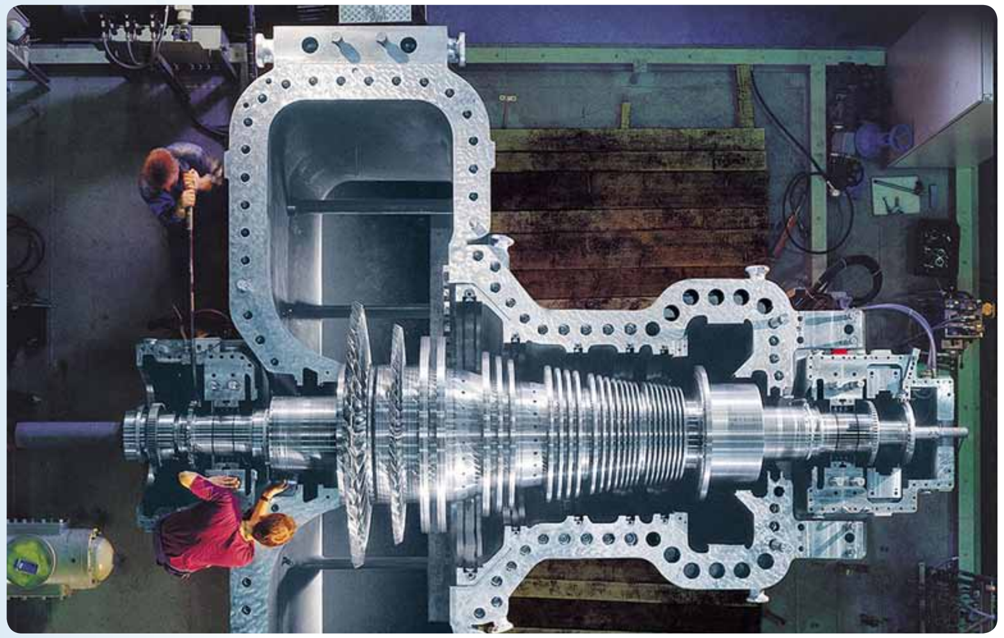
In retrospect, consistent process quality has turned out to be another benefit of automated production sequence planning and optimization. The software more or less forces implementation of the process which has been determined as the optimum, and thus contributes to consistent or improved product quality in an increasingly complex delivery chain.

8.5 Single-part manufacturing case study: MES from engineering to transportation logistics

Process description

Single-part manufacturing such as production of special-purpose machinery and industrial plants is characterized by small lot sizes of often one unit. Therefore, this industry optimizes not only the production and assembly process, but also associated engineering tasks as well as transportation logistics.

For a single-part manufacturer, a customer order initiates engineering processes instead of breakdown of the order into parts lists for production and assembly. Engineering then determines the assembly of the equipment from already available or special-construction parts. Therefore manufacturing is a combination of workshop management and partial new development. In both cases, external companies are generally involved and must be managed within the scope of the overall project.



Initial situation

A manufacturer of large plants valued at several hundred million Euro each, whose installation limited the use of standard or multiple-use components was faced with the following situation.

Over the years and across the entire chain of engineering, planning and coordination of internal and external manufacturing, material and inventory planning, pre-assembly, transportation and final assembly, a multitude of dedicated tools had been developed by the respective departments. Some of these were home-grown developments while others had been purchased as standard market solutions. Application consistency including login, operation, and data exchange was not enforced and could not be implemented with reasonable means.

MES solution

The standalone solutions had to be replaced by an MES. The nature of the situation required a comprehensive MES instead of using dedicated MES tools. Only a comprehensive MES allows planning, monitoring, and ongoing analysis using dedicated indicators for the continuous improvement process (CIP) for the above value chain. Continuous analysis means that after the introduction of MES, every customer project is planned, coordinated, and evaluated using the now available tools.

Interestingly, improving production efficiency and reducing costs were not primary objectives. Instead, the MES implementation had the two following main goals:

a) Replacement of the multitude of standalone IT solutions whose operation and maintenance resulted in numerous time-consuming and unmanageable activities. Over the course of several projects, the associated costs added up significantly.

b) Improving delivery integrity and avoiding penalties and additional costs (transportation logistics) by transparent and traceable project planning.

8 ADDED VALUE AND BENEFITS

Added value and benefits

For the objectives listed under a), the following table provides the savings potential for specific items:

Tasks	Potential of annual savings in €	Maintenance
Monitoring of client- and production orders and projects	24.000	Tool support for cost tracking/project controlling 10 project managers*4h/month*50€
Genration of reports	not named	Past: internally via Access and ODBC; Excel-sheets; definition, adaptation, packing of cataloges; programming reports; achieve access
Abolition of search-procedures in third party systems	108.000	Dates, progress, search and request for information Affects 10 employees*ca. 10h/month*60€ + 10 empoyees ca. 5h/month*60€
Project reporting	39.000	Automatic generation and distribution of reports (MIS) 30 employees*2h/month*50€ 10 employees*0,5h/month*50€
Effort for external orders - requests Effort for external orders - offers/orders	12.500 6.250	eProcurement 1.000 requests/year - 15 min. per request 500 orders/year - 15 min. per order
No isolated solutions - no home made developments	not named	Reduction of maintenance costs
No double data entries, no double systems	40.000	2 employees 1h/day + 1 employee 2h/d
Allocation of documents directly to order via document management (techn. drawings)	not named	
Simple PDA-operation by touch screen or barcode readers	62.000	1.500 PDA-events/day*10h savings of entry efforts*200 working daas *68€/h
Reduction of meeting and coordination efforts by unified data base and improved transparency of processes	54.000	In summary 24h/week* 45 weeks
Estimation of annual savings excluding the not named tasks	345.750	

Table 9: Annual savings potential

As mentioned under b), keeping scheduled delivery dates was another important objective. The reasons for this objective are avoidance of possibly very substantial contractual penalties and transportation reorganization cost. In this industry, transportation is a major cost factor because it requires special trucks, lifting equipment, rail cars, or ships which have to be booked months in advance.

Subject	Potential of savings (€/year)
Contract penalty if plant value is about 100 Mio. € (per plant)	500.000
Reorganisation of transportation logisitcs	125.000

Table 10: Saving potential due to increased delivery integrity

The MES introduction provided cost as well as schedule transparency which resulted in increased planning security. The introduction of the MES increased delivery integrity to the point that the plant manufacturer was no longer subject to any contractual penalties and entirely eliminated transportation reorganization cost.

8.6 Paper industry case study: production efficiency improvements

Process description

Production facilities in the paper industry produce paper and board from large quantities of groundwood, pulp, and recycled paper together with water, chemicals and additives. The products range from lightweight tissue to heavy cardboard, which are subject to high quality requirements regarding properties such as basis weight, caliper, brightness, and printability. In paper and converting plants, controlling and visualization of material flows as well as continuous and comprehensive quality monitoring and traceability present crucial challenges.

Initial situation

The pulp and paper industry depends on efficient logistical and technological processes throughout its entire production chain. In the last few decades the evolution of computer-based standalone solutions as well as great variety of interacting solutions has been significant. In order to further improve production efficiency and transparency, the individual systems require better functional interconnection. The objective is to increase the total plant efficiency (OEE) by reducing inventory levels of raw material, intermediate and finished goods and by optimized use of energy.

MES solution

In close cooperation between the automation vendor and plant operator, modern and comprehensive MES solutions based on standardized platforms were introduced in two paper plants, one in Europe and the other in the USA. The MES solutions contribute to smooth coordination of production and material flows, provide decision support, and enable the visualization and documentation of important production and quality data.

Added value and benefits

For both plants, the comparison of production data before and after implementation demonstrates considerably improved profitability as a result of the MES introduction. Production efficiency increased by 1,2 % and 4 % respectively, largely because of reduction of trim loss and improved production quality. The intermediate inventory levels decreased by 25 % and 35 % respectively, freeing up 6,25 million Euro and 2.3 million Dollar of capital. In the European plant, customer complaints dropped by 59 %. Until the introduction of the MES system, this was one of the most significant problems of this paper manufacturer. MES increased annual profits by 4,5 million Euro and 2,2 million Dollar respectively.

Further information
The MES provides extensive production status reporting and flexible production adjustments. The material flow transparency across the entire production chain results in improved customer service and more accurate delivery forecasts. In many cases product quality improves at the same time, because production flow can be more accurately controlled and requirements / recipes become more accurate and better traceable (figure 20). In particular for special products that are used in the food and beverage industry, traceability is becoming increasingly necessary.

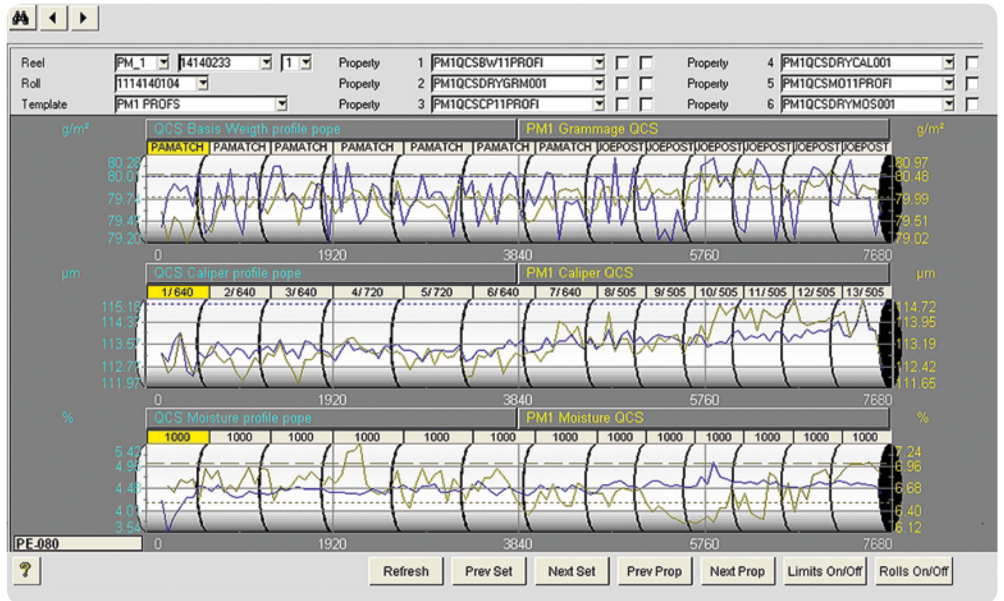


Figure 20: Traceable quality parameters for every roll and production

9 Summary and outlook

This brochure would not be complete without providing an outlook on upcoming developments and the future of MES.

From the late 80's to the mid 90's, the concept of MES was primarily characterized by individual customerspecific MES projects. While many were successful, some struggled with software development difficulties which were typical of that time – incomplete specifications, poorly projected development costs as well as cost overruns and missed deadlines up to the cancellation of entire projects. The initial MES euphoria gave way in some respects to disillusionment, and deployment and benefit of MES tools were viewed more skeptically. This resulted in uneven proliferation of MES applications across different industries which is still noticeable today. The higher the complexity, production flexibility, and number of product variants, the more production benefitted from using MES modules and the more they were accepted. Today, large series production, for example in the automotive industry, would be unthinkable without MES.

The purpose of this brochure is to illustrate the potential of MES solutions for applications in different industries and to provide a supplier-independent overview of currently available and feasible solutions. The troubles of early MES implementations have been solved. Both users and suppliers have learned their lessons and created a common understanding and language based on standards such as IEC 62264. Instead of being implemented as individual projects, MES solutions are largely assembled from configurable modules. The configurable portion usually represents 60 to 70 %, and the customer-specific extensions make up 30 to 40% of the functionality.

Additional standardization of data structures based on established corporate execution models and of transparent data transfer between applications will substantially advance innovation and deployment of MES applications.

While the complexity of the applications requires continued examination of the success and benefits of MES projects, many projects have repeatedly proven the economic benefit of MES. The MES objectives must continue to be based on individual requirements and implemented accordingly. At the same time, increased industrial expertise regarding personnel requirements and quality ensures a higher optimization yield.

The early (re)arrangement of local and enterprise-wide IT infrastructure is particularly important. This applies to network architecture and basic data structures as well as security.

The success of future MES projects is almost guaranteed if long-term MES maintenance cost and personnel are included in the project.

And what does the future hold?
As shown above, the integration and interconnection of all aspects of production scheduling and execution as well as the corporate information flow are both technically feasible and economically necessary. Therefore, further proliferation of MES solutions in all industries is only logical. This will extend to the point at which solutions and systems at level 3 of the enterprise model (production operations management) will be as common as today's IT solutions at level 4 (business planning and logistics) and automation solutions at level 2 (process management and data acquisition).

Integration in the enterprise will increasingly need to consider all three axes of collaboration within the enterprise:

- Enterprise axis: Planning – Management – Production
- Supply chain axis: Supplier – Production – Customer
- Life cycle axis: Development – Production – Support

In view of these requirements, the concept of a single, all-encompassing MES solution must be retired. The future lies in a collaborative environment of multiple cooperating applications which are distributed across multiple functional levels (ERP, MES, and process control), corporate areas (production, maintenance, quality, and inventory management) and axes (enterprise, supply chain, life cycle).

Technologies such Service-Oriented Architecture (SOA), transactional data exchange via XML, and web services for easy access of other applications enable this kind of transformation.

Users must be empowered to optimally fulfill their tasks by providing them with account and web based portals for accessing applications and overviews of all relevant corporate levels. At the same time, the specific distribution and interaction of the applications should be user-transparent.

In the future, this will increasingly involve concurrent simulation and real-time optimizations. These will determine the best production alternatives based on specified criteria, and thus support the decision process.

The MES future promises extra value and benefits for the users and exciting development opportunities for the vendors.

In conclusion, the members of the working group and the authors of this brochure would like to wish all readers a successful implementation of their MES projects.

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