



MES Services in the Automotive Industry

Alexander Schmidt, Dr. Boris Otto, Dr. Alfrid Kussmaul (HP)

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**University of St. Gallen -
for Business Administration, Economics, Law
and Social Sciences (HSG)**

Institute of Information Management
Müller-Friedberg-Strasse 8
CH-9000 St. Gallen
Switzerland
Tel.: ++41 / 71 / 224 2420
Fax: ++41 / 71 / 224 2777

Prof. Dr. A. Back
Prof. Dr. W. Brenner (managing)
Prof. Dr. R. Jung
Prof. Dr. H. Österle
Prof. Dr. R. Winter

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List of Abbreviations

DCS	Distributed Control System
DNC	Distributed Numerical Control
ERP	Enterprise Resource Planning
IT	Information Technology
ISA	International Society of Automation
MES	Manufacturing Execution System
MESA	Manufacturing Enterprise Solutions Association
MRP	Material Requirements Planning
OEM	Original Equipment Manufacturer
PLC	Programmable Logic Controller
SCADA	Supervisory Control and Data Acquisition
SOA	Service-Oriented Architecture
WIP	Work in Progress

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1 Introduction

1.1 Study Context

The study on MES Services in the automotive industry forms the second phase of a collaborative research project. It is based on the results of the first phase, which are documented in the working paper “Integrated Manufacturing Execution – Functional Architecture, Costs and Benefits” (report number BE HSG/ CC CDQ2 / 17). The working paper defined Manufacturing Execution Systems (MES) and distinguished them from Enterprise Resource Planning (ERP) systems and shop floor automation systems, and it specified functional building blocks of an MES in the automotive industry (Schmidt et al., 2009). More specifically, the working report answered questions regarding the functional scope of MES, the underlying terminological understanding of the term “Manufacturing Execution Systems”, to which layer (ERP, MES or Shop Floor) functionalities can be assigned with a minimum overlap etc.

The working paper provides a terminological basis for MES and specifies necessary manufacturing related application functions on a conceptual level. With that as a foundation, the working paper at hand intends to go one step further and detail the findings from the IME project. More precisely speaking, the working paper aims at identifying and specifying fine-grained functional services for each of the functional building blocks from the IME project (Schmidt et al., 2009, Schmidt et al., 2011). Consequently, the results of the working paper at hand complement the former research results by adding a more implementation related view to the relatively coarse-grained, conceptual requirements definition for MES in the automotive industry from the first study report.

1.2 Study Objectives

The study aims at the advancement of the state of the art in research and practice towards a MES Reference Architecture that contains three building blocks:

- MES Service Map, which defines standardized functions and services;
- Semantic MES Information Model, as a means for standardizing manufacturing related information objects for a common language;
- Basic MES Architecture patterns.

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The study acknowledges the complexity of the task at hand. As a consequence, it does not aim at completeness of results with regard to functional details, but rather at applicability and feasibility of the concepts and tools proposed.

1.3 Document Structure

The working paper is structured as follows: After the introductory section, Section 2 outlines the study design including the underlying research approach (Section 2.1) and gives a short presentation of the three automotive manufacturers participating (Section 2.2). Thereafter, Section 3 lays the conceptual foundation for the working paper by summarizing the state-of-the-art knowledge base on MES and the issue of service identification and specification. For this purpose, the section also defines essential terms (the term “service”, for example) of the working paper. While Section 4 introduces the procedure model for service identification and specification as well as the intended artifacts resulting from application of the procedure model in general, Section 5 presents the study results, i.e. the artifacts instantiated for the automotive manufacturers participating. Section 6 concludes the working paper with a brief summary of the research results and an outlook on future research challenges.

2 Study Design

2.1 Research Approach

The study follows a design-oriented research approach which is based on collaboration with partners from the practitioners’ community. The approach mainly covers four phases, following the principles of consortium research (Österle and Otto, 2010):

- Analysis: This phase aims at the identification of the problem and the specification of the solution. Both activities were carried out in the first phase of the IME project and are documented in the aforementioned working paper.
- Design: This phase makes use of accepted service identification and design techniques. It was carried out by the authors and continuously reviewed by subject matter experts from HP. In particular, the MES Information Model and the MES Services Map are models according to March and Smith (1995) , thus typical design artifacts.
- Evaluation: The demonstration and assessment of the feasibility and applicability of the design artifacts were performed in workshops with the partner companies. The

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representatives of the partner companies granted the researchers access to their knowledge and experience, and they evaluated the different versions of the design artifacts. Illustrative scenarios were used (during service identification and description, for example) to jointly walk through the results. The workshops were carried out as semi-structured on-site focus group interviews (Cavana et al., 2001, p. 153-159) with varying numbers of participants (between two and six) from both IT and manufacturing departments (e.g. plant managers). The interview questions were open-ended. Additionally, we analyzed documents provided by the workshop participants, such as existing process models and service maps, which complemented the information gathered during the interviews.

- Dissemination: The results are made publicly available in outlets of both the scientific and the practitioners' community. One information dissemination product is the report at hand.

Considering the differences between component manufacturing plants and assembly plants in the automotive industry, which became evident in the course of the IME project and which were explicitly addressed in the working paper "Integrated Manufacturing Execution – Functional Architecture, Costs and Benefits", the scope of investigation for the follow-up project was deliberately limited to component manufacturing plants. This allowed us to analyze MES functionality in more detail and to identify and describe a more homogeneous set of MES services and information objects.

The study ran from December 2009 until August 2010.

2.2 Study Partner Companies

2.2.1 AUDI AG

AUDI AG is a German automobile manufacturer headquartered in Ingolstadt, Germany. It has been an almost wholly-owned subsidiary (99.7 %) of the Volkswagen Group since 1964. The company employs about 58,000 people, generating annual revenues of approximately 30 billion Euros (2009). The Audi Group itself is subdivided in several national subsidiaries and manufactures cars in seven international manufacturing sites (Ingolstadt and Neckarsulm in

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Germany, Brussels in Belgium, Györ in Hungary, Changchun in China, Bratislava in Slovakia, and Aurangabad in India).

Focusing on component manufacturing, participants for the interviews at Audi came from the manufacturing plants of AUDI AG in Ingolstadt (with an output of more than 550,000 cars per year and 32,000 employees in 2008) and Neckarsulm (approximately 300,000 cars per year and 13,000 employees in 2008), the two biggest manufacturing plants of the company (with regard to yearly vehicle production).

From AUDI AG, the following representatives participated in the assessment workshops:

- Christoph Lubkoll, Head of IT Services Neckarsulm, and
- Tiberius Winkler, Project Manager in the Process and System Integration Department in Logistics and Component Manufacturing.

2.2.2 BMW AG

The Bayerische Motoren Werke (BMW) AG is a German automobile and motorcycle manufacturing company, which was founded in 1916. It is headquartered in Munich, Germany. The company employs approximately 100,000 people, generating annual revenues of more than 50 billion Euros (2009). Today, the BMW Group is the parent company of the MINI brand as well as of Rolls-Royce Motor Cars. BMW manufactures cars in 24 sites spread across 13 different countries.

The workshop participants from the BMW Group mainly belonged to the component manufacturing plant in Landshut, Germany, but also included participants from the Center of Competence for manufacturing related IT systems, which has company-wide responsibility for MES.

From BMW AG, the following representatives were the main contact persons in the study:

- Robert Peter, Head of CoC “Anlagennahe Systeme” and
- Harald Scheder, Head of IT, plant Landshut.

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2.2.3 Volkswagen AG

Volkswagen (VW) AG is a German automobile manufacturer headquartered in Wolfsburg, Germany. With annual revenues of 105 billion Euros and a total of approximately 370,000 employees in 2009, the Volkswagen AG is the largest European automobile manufacturer and currently ranks among the top three automakers in the world. It unites numerous automobile brands, among them Audi, Bentley, Bugatti, Seat, and Skoda. Volkswagen AG currently operates 60 manufacturing sites in 21 different countries.

Our interview partners at VW were affiliated to the ITP Components department. Within the company, the ITP Components department is responsible for process and IT development and for maintenance of all component manufacturing plants worldwide. Components in this case cover the whole spectrum, including both simple components, such as pressed or foundry parts, and complex components, such as gears or engines.

From this department, two leading representatives participated in the assessment workshops:

- Hans-Christian Heidecke, Head of ITP Components, and
- Ingo Höfer, Software Engineer at ITP Components.

3 Related Work

3.1 Manufacturing Execution Systems

Manufacturing Execution Systems are a relatively new class of information systems designed particularly to support shop floor processes and their integration into companies' information system architectures (Louis and Alpar, 2007). MES constitute the interface between the planning (ERP) layer and the production layer. They are an essential component for vertical integration, as illustrated in Figure 3-1. The three layers can also be referred to as Company Management (for which ERP systems are the most common tools), Production Management (done by MES), and Production (supported by systems for machine control and acquisition of manufacturing data) (Günther et al., 2008). The latter usually contains hybrid hardware/software systems, such as Distributed Control Systems (DCS), Programmable

Logic Controllers (PLC), Distributed Numerical Control (DNC), Supervisory Control and Data Acquisition (SCADA) systems, and other control systems designed to automate the way in which products are manufactured (MESA, 2000).

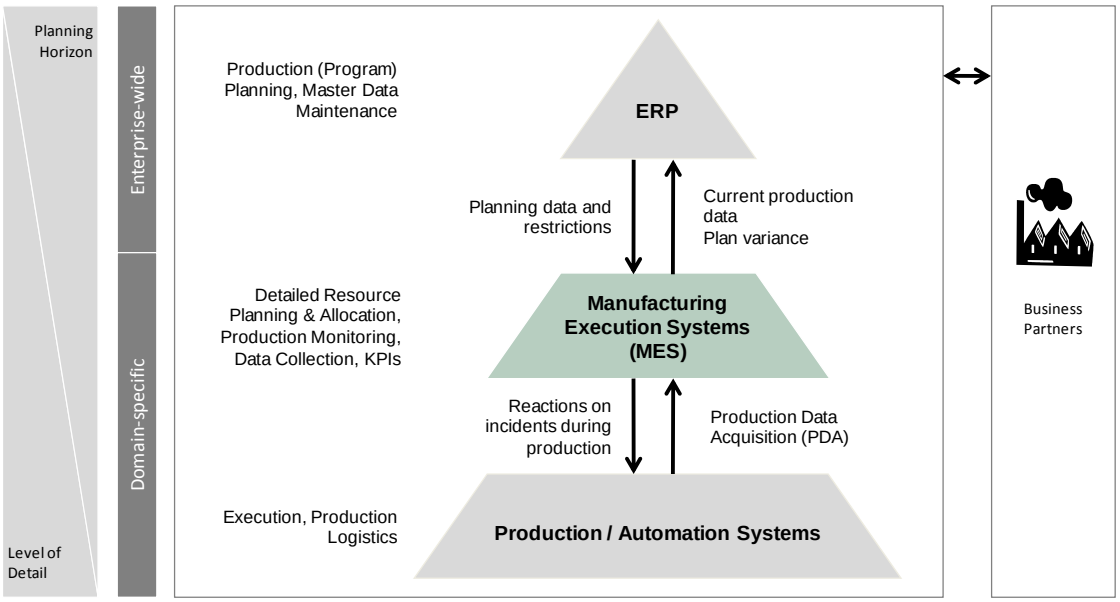


Figure 3-1: MES as connector between ERP and shop floor [based on (Albert and Fuchs, 2007, Louis and Alpar, 2007)]

In contrast to ERP systems, which generally provide very broad functionality covering all business functions of an enterprise along its operational supply chain, MES aim at enabling companies to quickly respond to events occurring in the production process (reactive detailed planning). MES take a microscopic, more granular view on production data (often restricted to a single plant or production area), compared to the macroscopic, holistic view of ERP systems, and therefore are intended to compensate one of the main shortcomings of ERP system production modules: the incapability of providing integration of real-time manufacturing data generated on the shop floor (Wannenwetsch and Nicolai, 2004). This incapability basically results from an inadequacy of ERP production plans to respond to changing demands or deviations in the manufacturing process. Neither are these systems capable of handling the enormous amount of data coming from the shop floor, nor do they provide short response times and sufficient levels of detail (with regard to the modeling of the production process, for example) (Louis and Alpar, 2007). It is this gap that MES are trying to fill.

As MES in the past have not been subject of extensive scientific research (some exceptions being the recent works of Kletti (2006), Sauer (2004) and Schäfer et al. (2009), a well-established definition of the term has not been given so far. However, there are leading standardization organizations in the domain of manufacturing integration, most notably the Industry, Systems, and Automation Society (ISA) and the Manufacturing Execution Solutions Association (MESA), that have put some effort into finding a common definition and specifying generic MES functionality (ISA, 2000, ISA, 2005) and (MESA, 2000, MESA, 2004).[1] So MES are defined as "systems that deliver information enabling the optimization of production activities from order launch to finished goods. Using current and accurate real-time data, MES guide, respond to, and report on plant activities as they occur. The resulting rapid response to changing conditions, coupled with a focus on reducing non-value added activities, drives effective plant operation and processes." (MESA, 2000). This definition implies the following characteristics of MES:

- high level of detail (data acquisition from manufacturing processes),
- relatively short planning horizon (reactive planning),
- bi-directional communication to both ERP systems and shop floor systems (interfacing).

The ultimate goal of MES can therefore be described as increasing transparency on the manufacturing process and, as a result, establishing horizontal and vertical (closed) control loops (Kletti, 2006). These control loops allow for prompt reaction to incidents on the shop floor, as information is directly fed back to overlying planning systems (such as ERP) to trigger respective measures as well as to subsequent manufacturing steps (horizontal integration).

A major challenge with regard to the model shown in Figure 3-1 lies in a clear demarcation of the three layers[2]. This is a difficult task, as certain enterprise functions may be supported

[1] A more detailed presentation of the standards is included in the following section.

[2] The problem of demarcating the three layers with regard to their functions is discussed in more detail in the study report "Integrated Manufacturing Execution – Functional Architecture, Costs and Benefits" (report number BE HSG/ CC CDQ2 / 17).

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by a number of information systems located in more than one layer (e.g. quality management by ERP *and* by MES applications, production data acquisition by control systems on the shop floor *and* by MES applications), leading to a high degree of interconnection between the systems. Nevertheless, a clear distinction appears useful, as the systems differ regarding the degree to which they support functionality for manufacturing planning compared to manufacturing execution. We follow this argumentation and distinguish the three layers ERP, MES, and Shop Floor mainly based on two parameters (see Figure 3-1): the planning horizon, i.e. the period of time for which different tasks are scheduled, and the level of detail of the information managed. By rule of thumb, ERP systems cover the mid- and long-term planning for a time horizon of at least one day (up to several weeks or months), MES handle production planning information ranging from one hour up to one day, and on the Shop Floor layer time intervals scale down to the level of several minutes. As every minute of production stop due to machine or tool failure directly leads to loss of money, rapid, ad-hoc decisions need to be supported in production management and execution (Kletti, 2006).

3.2 Services, Service Identification and Service Specification

Service-Oriented Architectures (SOA) are defined as a "paradigm that supports modularized exposure of existing application functionality to other applications as services" (Nadham, 2004). SOAs are supposed to allow for flexible combination of application systems made up of discrete subsystems (i.e. services) in order to serve individual requirements (Krafzig et al., 2004, Leymann, 2003). The SOA principle is seen as a promising approach for accomplishing integration of heterogeneous application landscapes (Kohlmann, 2007). Confronted with historically grown, heterogeneous application landscapes in the production environment, automakers are increasingly recognizing the potential of the idea of service orientation (Vogel, 2009).

Being the central components constituting a SOA, services are abstract, exhaustively specified, independently usable functional components (also software components) that support process activities (Kohlmann and Alt, 2007). Such services have well-defined, stable interfaces and provide other applications access to reusable application functionality on the basis of broadly accepted standards (Legner and Heutschi, 2007).

Many authors have dealt with the challenges of identifying, specifying and designing services. Regarding the latter aspect, a number of authors have identified fundamental design principles (Heutschi, 2007, Thomas et al., 2009, Newcomer and Lomow, 2005, Papazoglou and Georgakopoulos, 2003, Kohlmann and Alt, 2007). An overview of such design principles is given in Table 3-1. Design principles also need to be considered when it comes to identifying and specifying services.

Design principle	**Description**
Interface orientation	• Comprehensive, standardized specification of services • Stable service contracts
Interoperability	• Technical and conceptual interface standardization • Use of open, broadly accepted standards
Autonomy and modularity	• High service cohesion and weak logical coupling • Loosely coupled communication
Demand/Process orientation	• Service granularity oriented towards business concepts or business processes • Generalized service output
Abstraction	• Platform independent and implementation independent service descriptions

Table 3-1: Service design principles

The modeling of services, comprising both service identification and service specification, is also an issue that has been extensively dealt with in numerous scientific publications. A comparison of existing approaches is given by Kohlmann and Alt (2007, pp. 182f.). In this overview, the authors assess the different approaches by means of certain criteria (comprehensiveness of service specification, graphic representation of service landscapes, linking of top-down and bottom-up procedures, for example) and derive a comprehensive methodology for service identification and specification (Kohlmann and Alt, 2007). Since this methodology has proven to be effective in a number of enterprises, the authors of the study decided to use it for their case (services for MES in component manufacturing in the automotive industry) as well. As the original methodology has its focus on the finance industry, the methodology to be applied for the present study was slightly adapted and results from the IME working paper were integrated.

The specification of a service is essential for being able to understand and reuse the service. A service specification defines a service according to predefined principles. It contains all the information required by different stakeholders for design, development, maintenance and use

(Heutschi, 2007, Josuttis, 2008). From various publications on the issue (Stojanovic, 2005, Turowski et al., 2002, Papazoglou and Georgakopoulos, 2003), Vogel (2009) has derived four categories of service specification (see Figure 3-2).

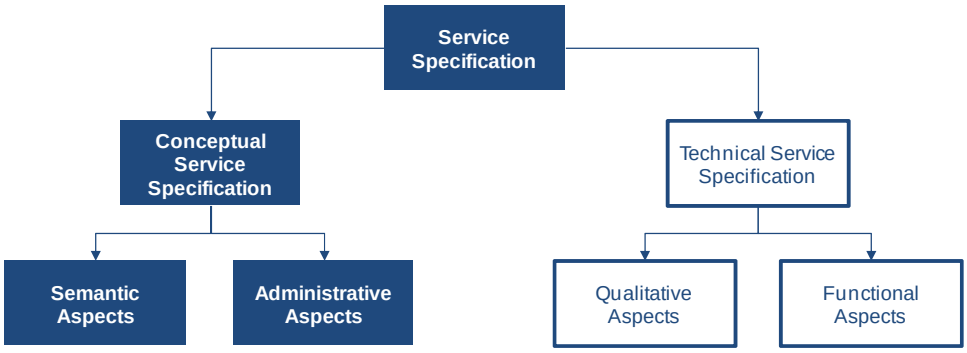


Figure 3-2: Categories of service specification [following (Vogel, 2009)]

Whereas the Technical Service Specification rather comprises implementation related aspects, the Conceptual Service Specification focuses more on information regarding the context the service is used in, the information objects that are used, and organizational aspects. In Table 3-2 each of the four categories is described in more detail.

Level	Category	Description
Conceptual	Semantic	Specification of functional behavior (invoke semantics, data semantics) of the service in a process context, and specification of mandatory pre- and post-conditions for correct execution of the service Examples: service operation, information objects used, input/output
	Administrative	Aspects with regard to use and maintenance of a service Examples: functional service name, domain, business contact person, version number
Technical	Functional	Information required to ensure a service's technical communication capability Examples: technical service name (or service identifier), data formats/types, network address
	Qualitative	Non-functional requirements and guidelines regarding the use of a service in terms of security mechanisms and quality-of-service parameters Examples: security, response time, availability

Table 3-2: Description of categories of service specification

As the study focuses on the specification of services primarily from a conceptual perspective, and as the study – at this stage of the research process – wants to exclude implementation specific aspects, the specification of services is limited to semantic and administrative aspects as defined in Section 4.1.

4 Research Methodology

4.1 Terminology and artifacts

Figure 4-1 shows the design objects for identifying and specifying services in the form of a simplified meta-model. The terms used in the meta-model are clarified in the following sections in order to allow for unambiguous comprehension of all subsequent explanations of the paper.

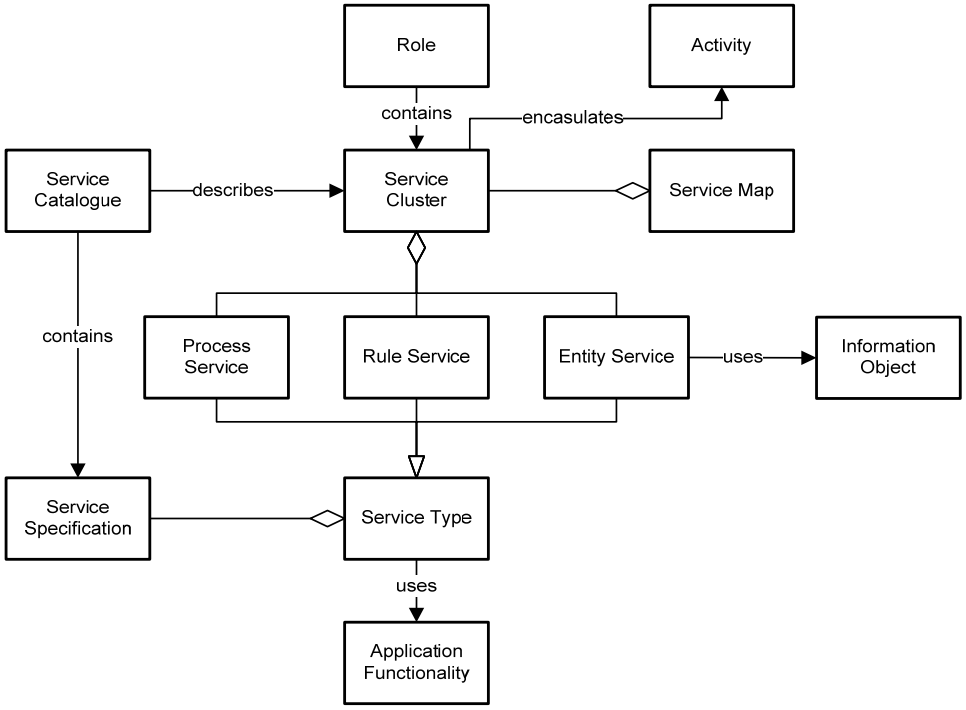


Figure 4-1: Design objects for service identification and specification [following (Kohlmann, 2008)]

As already mentioned in Section 3.2, we transferred the methodology for service identification and specification developed by Kohlmann (2008) and Kohlmann and Alt (2007) to the research area of this study and applied it in a slightly modified form. The same applies to all underlying concepts (service classification, for example) as well as to the central design results.

The three-partite division of *Service Types* into *Process Services*, *Rule Services*, and *Entity Services* has been made by Kohlmann (2007) upon analyzing scientific publications as well as terminologies of software manufacturers. All *Service Types* are exhaustively specified functional building blocks encapsulating *Application Functionality*. However, they differ

with regard to the type of functionality made available by the Service (Kohlmann, 2008, Kohlmann and Alt, 2007):

- *Process Services* cover functionality which can directly be derived from the business process model, and they support process activities. They can invoke other Process Services, Rule Services or Entity Services during the time they are being executed.
- *Rule Services* encapsulate business and validation rules. They are invoked by Process Services using these rules (during calculation, for example).
- *Entity Services* allow operations (create, read, update, delete, for example) on an Information Object. They provide a standardized view on the Information Object, and they ensure consistent creation and modification of the data of an Information Object by Rule Services and Process Services invoking them.

Several Process Services, Rule Services, and Entity Services can be grouped according to their functional and logical similarity to form *Service Clusters* (Kohlmann, 2008).

Services and Service Clusters are graphically represented in *Service Maps*, which can have different degrees of detail. Besides an overall view showing Service Clusters only and a detailed view in which for the entire application area all Service Types including relations between them can be modeled, also domain specific or process specific creation of Service Maps is possible (Kohlmann, 2008).

In addition to the Services and the relations between them being displayed in overviews by means of graphical representation, each Service needs to be specified in detail. For *Service Specification* the framework from Section 3.2 was used, with a focus on conceptual service specification aspects. The attributes specified for each Service in the workshops (regardless of the Service Type) are summarized in Table 4-1.

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Administrative service aspects	
Functional service name	Unambiguous name for the Service
Domain	Functional domain the Service is assigned to
Service category	Classification of the Service (Process Service, Rule Service or Data service
Semantic service aspects	
Description	Short description of the operation encapsulated by the Service and of the result of the Service's execution
Encapsulated activity	Link to those Activities for which functionality is encapsulated by the Service (reference to business process model)
Information objects	Link to Information Objects used by the Service (reference to information model)
Input / Output	Information, resources and parameters needed to execute the Service or resulting from the execution of the Service
Invoked by / Invokes	List of Services invoking or being invoked by the Service
Reutilization	Link to Service Clusters in which the Service is used

Table 4-1: Aspects of conceptual service specification [following (Heutschi, 2007)]

Based on these aspects of conceptual service specification, a Service Description Template was put up that was used in the workshops to specify each individual service with the representatives of the OEMs participating (see Appendix A).

All Services specified (regardless of the Service Type) are stored and maintained in the *Service Catalogue*.

4.2 Procedure Model

The original procedure model for service identification and specification is described in detail in (Kohlmann, 2008). Figure 4-2 shows the procedure model with its five phases and all activities. Also shown are the most important input documents and the results of each activity.

The first phase, *Preparation*, aims at the specification of the research domain and the selection of appropriate models on the basis of which the Services are to be identified. Primarily, among these models are existing business process models (both as-is and to-be models) and the Function Maps developed for each OEM in the course of the IME project (Schmidt et al., 2009). For the „Defining MES Services for the Automotive Industry" project, the research domain was limited to component manufacturing. Due to this limitation, the

effort and the complexity of the *Analysis* phase following the *Preparation* phase can be reduced. Activity I.2 (Choose Classification Scheme) refers to the selection of the Service Types forming the basis of the identification and specification process. For this purpose, a number of classification concepts can be found in literature. The working paper follows the three-partite division of Service Types into Process Services, Rule Services, and Entity Services as outlined in Section 3.2 (which is a distinction that does not necessarily have to be followed in order to apply the procedure model successfully).

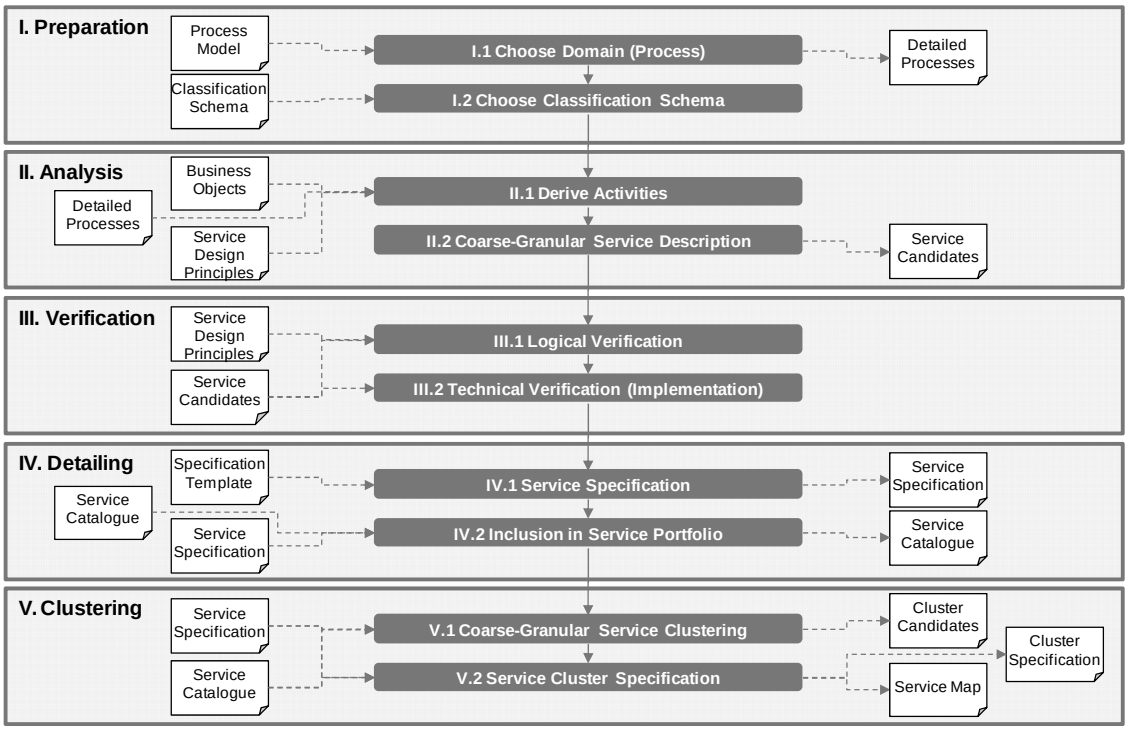


Figure 4-2: Procedure model for identification and specification of services [following (Kohlmann and Alt, 2007)]

If business processes have been modeled and documented only very roughly, they need to be further specified and broken down to discrete Activities in the *Analysis* phase. Activities form the basis for the identification of Service candidates, as the service design principles introduced in Section 3.2 (see Table 3-1) are applied to them. In addition, other criteria such as legal requirements, use of Services depending on place and time (Kohlmann, 2008), for example, should be taken into account. One aspect to be focused should be the identification of similar functionalities within a process, in order to foster reutilization of Services. The

coarse description of Service candidates as a result of Activity II.2 (Coarse-Granular Service Description) comprises the classification of each Service candidate either as Process Service, Rule Service or Entity Service, the naming of each Service candidate in compliance with the company's naming conventions, and the Service candidate's functional description. If the Service candidate is an Entity Service, the Information Object related to it has to be indicated.

The aim of the *Verification* phase is to check the validity of the Service candidates by means of logical and technical criteria. The process of verification is particularly important to ensure that a Service candidate's functionality is not provided by existing Services or Service Clusters already. Besides the need for compliance with the design principles outlined in Section 3.2, what should be ensured as well is that each Service candidate can be assigned to one single function of the Function Map only. The *Verification* phase ends with each Service candidate being checked as to whether it is capable of being (technically) implemented. This is done by comparing the Service candidate's encapsulated functionality with the already existing application logic and by estimating the effort needed for implementing the functionality.

In the fourth phase, *Detailing*, verified Service candidates are specified in detail, using the Service Specification Template (see Appendix A). First of all, based on the name the Service candidate was given in the *Analysis* phase, the result and the functionality are specified. After that, the Service context (Input / Output of the Service), the domain the Service is assigned to, and the necessary Information Objects need to be specified. Finally, the relations and interdependencies with other Services are specified (i.e. by which other Services the Service to be specified is invoked, and which other Services are invoked by the Service to be specified). The information resulting from the *Detailing* phase are particularly important with regard to the creation of the Service Map. If required, more information about a Service (regarding its quality, for example) can be added. After the specification of the Service is done, it is released for being documented in the Service Catalogue.

In the *Clustering* phase, finally, functionally similar services (in particular Process Services, Rule Services, and Entity Services that belong together) are grouped to form Service Clusters. The results of this phase are documented in the Service Catalogue too.

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5 Study Results

5.1 MES Service Map

The MES Service Map is the main result of the approach outlined in Section 4. It identifies standard MES Services and groups related Services into Service Clusters. In order to reduce complexity, the figure is restricted to Process and Entity Services as the main service types.

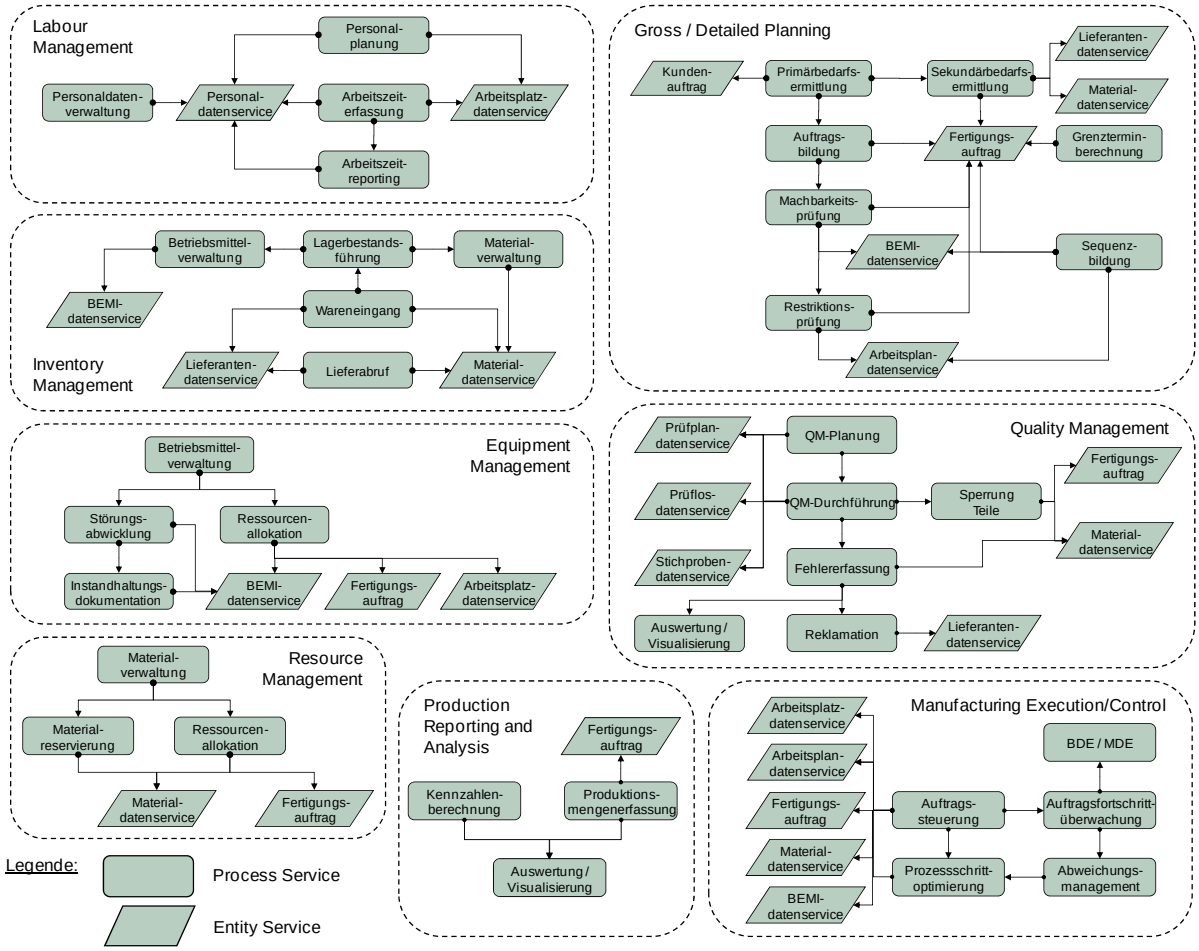


Figure 5-1: MES Service Map[1]

The MES Service Map contains 63 Services in 8 Service Clusters. The Service Clusters are:

- Labor Management: Labor Management comprises all Services related to managing personnel information, personnel time accounts, staff scheduling and capacity planning, assignment of personnel on schedule, and time and attendance reporting.

[1] Details are given in German in accordance with original project language.

- Gross/Detailed Planning: Gross Planning comprises all Services related to carrying out rough-cut scheduling, allocating production requirements into production sites, generating MRP, composing orders, and checking feasibility of the latter. Detailed Planning comprises all Services related to executing detailed planning, restriction checking, sequence scheduling, and creation of production orders and production plans.
- Production Inventory Management: Production Inventory Management comprises all Services related to collecting and managing stock information of materials, monitoring and accounting goods movement, and performing physical inventory.
- Resource Management: Resource Management comprises all Services related to ensuring availability of resources for processing, managing and processing WIP stock, tracking resource status, maintaining resource histories, altering schedules on floor plan, making reservations, and dispatching of resources.
- Equipment Management: Equipment Management comprises all Services related to managing and processing equipment information, providing equipment in production processes, ensuring scheduling for maintenance, responding to immediate problems, and performing maintenance reporting.
- Manufacturing Execution/Control: Manufacturing Execution and Control comprises all Services related to monitoring production orders, controlling and adjusting order sequences, comparing planned and actual production status, updating production plans, providing planning table functionality, locking parts and recording waste, notifying material movements to inventory management, and sending orders for in-process quality checks.
- Quality Management: Quality Management comprises all Services related to compiling quality and inspection planning, conducting and documenting quality inspection, providing information for production documentation, creating quality analysis reports, recommending improvement actions, and determining and controlling rework.
- Production Analysis and Reporting: Production Analysis and Reporting comprises all Services related to up-to-the minute reporting of manufacturing processes, long-term production analysis, visualizing of production data, and exception handling.

5.2 MES Information Model

The MES Information Model emerged as a "byproduct" of the MES Service Map. Figure 5 1 visualizes Entity Services as a major service type that allow for operations on information objects (see Section 4.1) necessary during the manufacturing process. Consequently, the underlying set of information objects constitutes the basis of the MES Information Model. As outlined in Section 3 the unambiguous semantic definition of information objects used within services is a key prerequisite for service description. As a consequence the MES Information Model materializes as an integral part of the service descriptions.

Information Objects were exemplarily identified and described during the bilateral workshops with the partner companies. In line with the project's constraint not to develop a complete model of MES Information Objects but to focus on the applicability of the approach, Figure 5-2 shows an example of a Service description including Information Objects and Input / Output information.

Service Description

Name	Fehlererfassung
Description	Wurde ein Fahler identifiziert, wird eine Fehlermeldung bzw. Qualitätsmeldung im SAP zur Dokumentation erfasst. Wurde der Fehler im Rahmen einer Qualitätsprüfung oder im Rahmen der 100%-Prüfung am Band gefunden, so erfolgt zunächst eine Separierung der fehlerhaften Teile sowie die Entscheidung, ob die Teile verschrottet oder gesperrt werden sollen. Anschliessend wird der Fehler im System unter der Angabe eines Verursacherschlüssels erfasst. In Abhängigkeit vom Verursacherschlüssel wird eine Lieferantenreklamation oder ein Eigenfehler initiiert.
Information Objects	Lieferant Material Teil
Input	Material-/Teilenummer, Lieferant, Charge/SLBZ-Nr., Paketreferenznummer Kaltbandnummer, Pressenstrasse, Kostenstelle, Ausführender, ggf. Messbericht Fertigungsgruppenleiter, ggf. Auftragsnummer, Güte und Abmessung, Meldender
Output	Fehlerklassifikation (Eigen- vs. Lieferantenfehler/Ausschuss) Fehlermeldung mit Ursachenschlüssel im System Fehlerschlüssel (Fehlerart, Fehlerort)
Classification	[X] Process Service [ ] Rule Service [ ] Entity Service
Invoked by	Qualitätsprüfung (Prüflos nicht in Ordnung-Entscheid) Fertigung BDE (Werker hat Fehler erkannt)
Invokes	Qualitätssteuerung Lieferantenfehler mailen Datenkorrektur/Ausschusserfassung
Reusability	
Encapsulated Activities	Fehlererfassung Ausschusserfassung
Domain Affiliation	Qualitätssteuerung
Service Cluster	Quality Management

Figure 5-2: Example of a MES Service description

The example describes the Service “Error handling” as an element of the Service Cluster “Quality Management”. Being a Process Service, it uses three Information Objects, namely Supplier, Material, and Part.

5.3 MES Architecture Analysis and Design

The third goal of the study is related to the analysis and design of the MES Architecture. These activities have been motivated by a conflict of the goals to be accomplished by MES in the automotive industry: On the one hand, the demand for increased efficiency and reduced costs in the management of MES calls for increased standardization of MES deployed. On the other hand, enlarged flexibility in terms of production and model range require MES to be capable of meeting custom-specific needs.

The bilateral workshops resulted in the understanding that management of MES architecture is a key success factor in overcoming this conflict of goals.

In detail, four business scenarios were identified:

- OEMs need to create and keep transparency on their MES landscape because they are required to by various business drivers;
- OEMs need to identify functional redundancies in MES support;
- OEMs need to identify potentials for MES harmonization and consolidation;
- OEMs need to identify “white spots” of insufficient MES support.

Figure 5-3 shows a concept of a tool supporting the analysis and design of a MES Architecture.

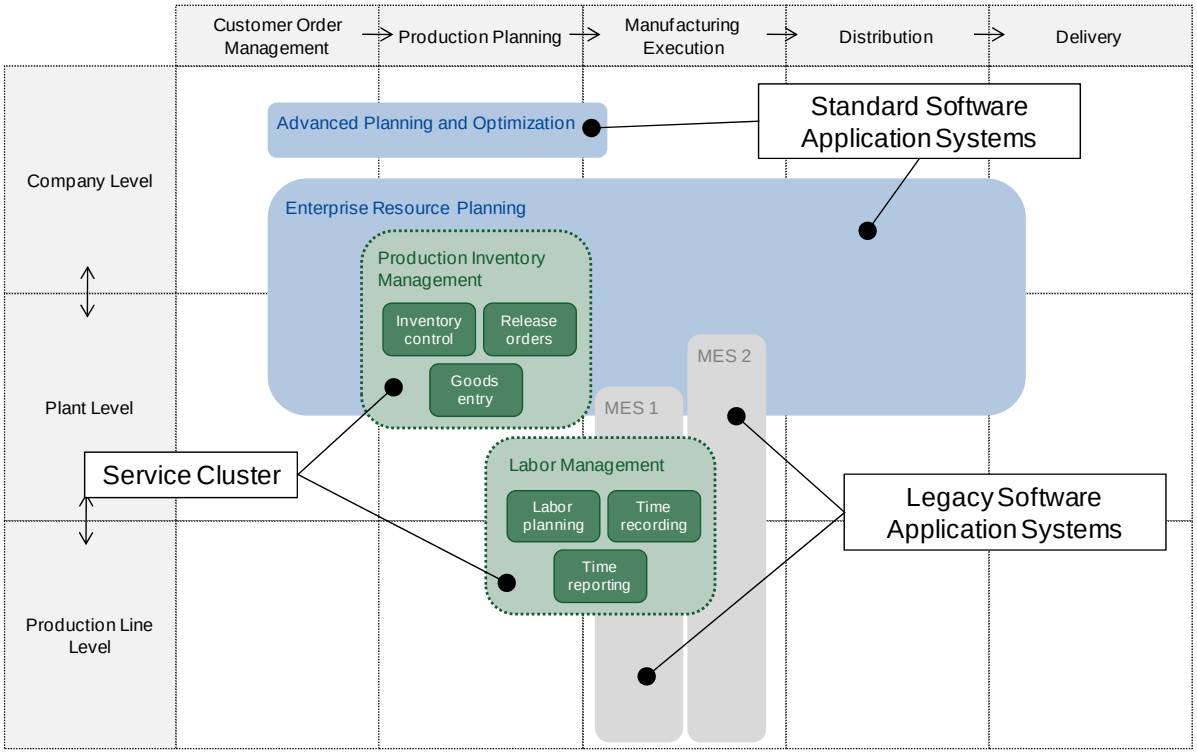


Figure 5-3: MES Architecture Analysis and Design

The illustration identifies two central dimensions of a MES Architecture, namely the (1) Customer Order Process, consisting of five phases from Customer Order Management to Delivery, and the (2) Planning Level, on which MES is applied ranging from a Company Level to a Production Line Level. Both dimensions form a matrix in which both Service Clusters and Application Systems or Application System Clusters, respectively, can be shown. The matrix allows for the identification of:

- overlapping functionality of application systems;
- missing functionality;
- identification of standard functionality;
- identification of required service clusters.

By identifying major use cases, the matrix lays the foundation for the design of a methodology and a tool supporting the analysis and design of a MES Architecture.

6 Conclusion

The study forms the second phase of a collaborative research project on the advancement of the scientific and practical body of knowledge regarding MES in the automotive industry. It aimed at the development of a MES Service Map, a MES Information Model, and “patterns” for the management of a MES Architecture. The results presented in Section 5 allow for the following conclusions:

- The MES Service Map supports automotive OEMs in their ambition to provide both flexible and, at the same time, standardized and scalable solutions in the MES domain.
- The project’s results show that within the automotive industry there is a significantly large “nucleus” in shared understanding regarding relevant services (e.g. the Service Cluster “Quality Management”).
- The project also delivers an approach to identify and describe MES Services in a methodological manner, which can be taken up by OEMs and service providers alike.
- The approach lays the foundation for a MES Information Model, which forms the shared semantics of information objects used by MES services in the automotive industry. First information objects are identified and described in the project.
- The MES Service Map, and in particular the distinction between Services and Service Clusters, enable the analysis and design of MES architecture patterns.
- A combined perspective from both a company structure and a customer order process point of view allow for identification of the “as-is” and the design of the “to-be” MES architecture, hence, the realization of standardization and consolidation potentials.

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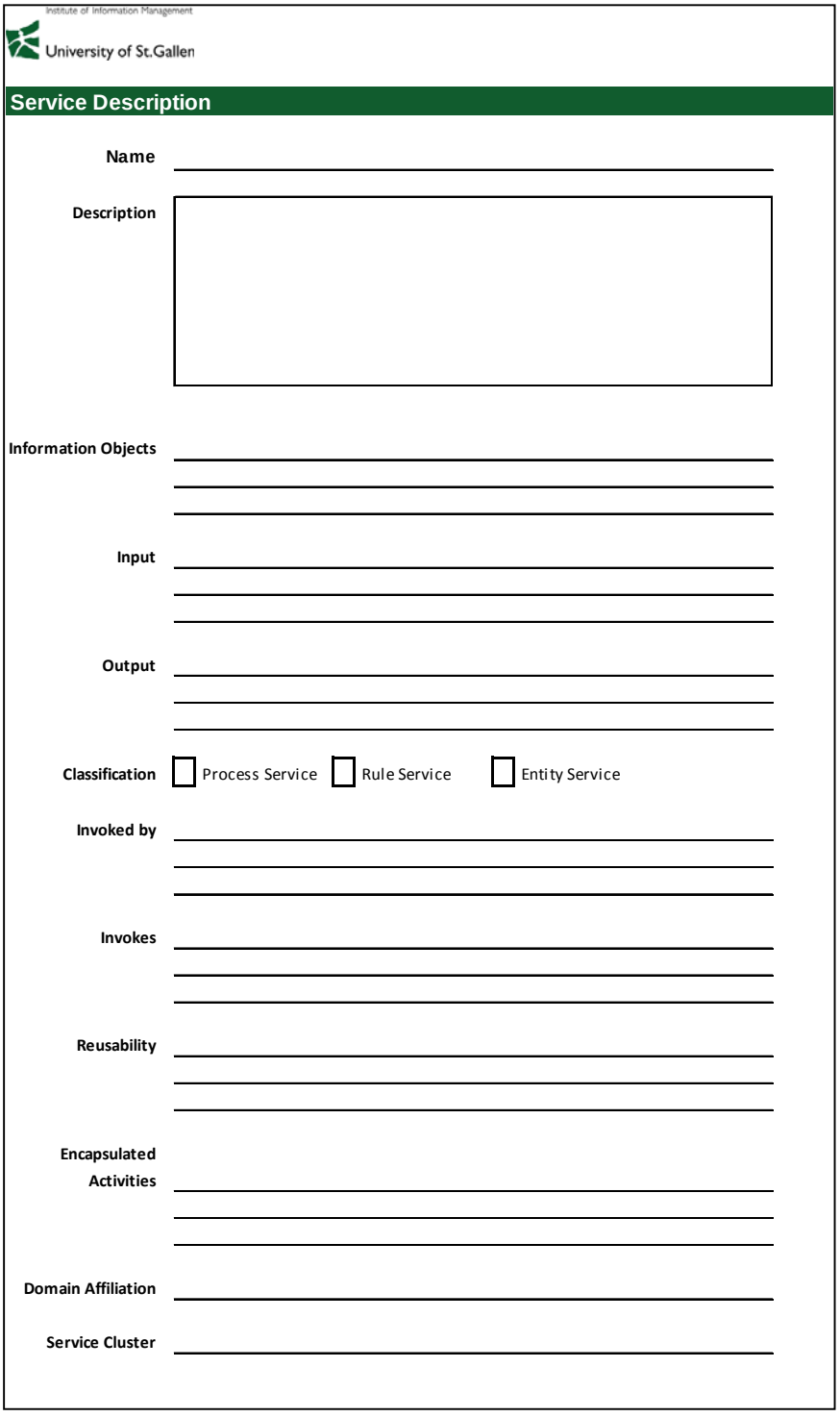
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Appendix A: Service Description Template



Institute of Information Management
University of St.Gallen

Service Description

Name _____

Description

Information Objects _____

Input _____

Output _____

Classification ☐ Process Service ☐ Rule Service ☐ Entity Service

Invoked by _____

Invokes _____

Reusability _____

Encapsulated Activities _____

Domain Affiliation _____

Service Cluster _____