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Operational Concepts For The Deployment Of AI-Supported Maintenance Strategies At Distribution System Operators

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Abstract

Climate change is leading to massive changes, especially in the areas of energy and mobility. As a connecting element of the energy and mobility transition, electricity grids will play a key role. Bidirectional energy flows and massive fluctuation in generation and consumption patterns lead to high stresses on components and systems, especially in the distribution grid. This confronts Distribution System Operators (DSOs) with new challenges to continue to ensure security of supply in an economical and resource-efficient manner. New maintenance strategies can enable operators to address these challenges. Novel sensors and artificial intelligence enable the technical use of methods such as Predictive Maintenance to detect and predict the probability of failure of critical components based on current condition data. Whereas Predictive Maintenance is already being used in many areas of the manufacturing industry today, the procedures are still new in operating medium-voltage switchgear in the distribution grid, which are critical for ensuring the security of supply. Today's maintenance processes are not automated and are based on Preventive Maintenance strategies and differ very much from those of production environments. For example, the used IT-systems differ as well as the level of involvement of service contractors and regulative requirements and limitations. The use of Predictive Maintenance in the operation of critical infrastructures therefore places special demands on existing maintenance strategies at DSOs to economically ensure security of supply. This paper proposes an operational concept consisting of a process model, IT-system landscape, and information logistics model compatible with the current process and system architecture to deploy new maintenance strategies at DSOs.

Keywords

Predictive Maintenance; Artificial Intelligence; Distribution System Operator; Operational Concepts; Energy transition; Mobility transition

1. Introduction

The focus of the German climate and energy policy is on a massive and area-wide integration of renewable energies [1,2] as well as on the integration of charging stations for electro-mobility into the existing power grid. The resulting numerous load fluctuations [3,4], e.g., caused by decentralized solar plants, as well as the temporally and spatially concentrated energy demand caused by charging infrastructure (eMobility), lead to very large loads that can lead up to overload on electrical equipment and components, such as switchgear. Literature and the conducted interviews show that typical switchgear assets are 30 years or older [5]. This imposes an immediate threat since operators are not aware about their current operation condition. Therefore, to achieve the goals of the energy and mobility transition while maintaining the same quality of supply, on the one hand, grid operators need an improved understanding of the current status and impending failures of components but on the other hand, have to deal with increasing cost pressure while maintaining the security

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of supply. Novel sensors paired with new Artificial Intelligence (AI) approaches are now making condition-based monitoring of assets for this use case technically possible [6]. The research project AproSys, which this work is part of builds upon the work of the finished project FLEMING, which was focused on a technical solution that consisted of low-cost sensor solutions paired with a corresponding machine-learning approach to classify condition states and make prognoses about the future state of components in switchgear.

In this paper, we concise an operational concept based on the current processes and procedures at distribution system operators (DSOs) as well as necessary system landscape to implement condition monitoring and novel maintenance paradigms in organizations of DSOs. This research should answer the question: *How does a holistic operational concept have to be designed to offer Predictive Maintenance Strategies in combination with legacy systems for medium-voltage switchgear at DSOs*? Therefore, we will describe the technical foundations this research focused on and then describe the used methodology to derive the operational concept. The overall objective is to contribute to a more stable grid by reducing maintenance costs and downtimes for distribution grid operators and to instruct the implementation of such systems into an operating business environment at DSOs.

2. Technical Foundations

In this chapter, we will introduce the technical foundations on which this research is based. Hence the status quo from the perspective of DSOs and switchgear will be explained as well as the relevant maintenance strategies.

2.1 Switchgears and their typical fault patterns

The total energy grid is composed of different grid layers with different properties and functions. As part of the research for a Predictive Maintenance application, we focused on medium voltage switchgear that connects medium and low voltage grids and is maintained by DSOs. As part of the distribution grid, it fulfils essential safety functions as well as controlling functions of the grid by providing energy to the typical "last mile" between homes and substations. Switchgears play an important role in the isolation of error patterns in the grid and its components. They come in metal enclosures and can be used in different operating settings such as urban buildings or dedicated substations in rural areas. Air is the most used insulation gas inside the switchgear. The subcomponent "circuit breaker" performs the error isolation function by closing or opening the affected circuit. [6] While the circuit breaker is crucial for error management, it has the highest failure rate of all components inside a medium-voltage switchgear. [9,6–8] The circuit breaker is composed of four components: Pole, Housing, Linkage, and Drive. The most common error patterns according to IEEE guidelines are: failure in the closed position, failure to close, failure to close (Properly), failure to stay closed, failure in the open position, failure to open, failure to open properly, and failure to stay open [9,6].

2.2 Common and AI-enabled Maintenance strategies

The terminology *Maintenance* refers to a comprehensive set of technical, administrative, and management procedures carried out during an object's lifetime to keep it in working order or return it to it [10]. The most common maintenance strategies are: Preventive Maintenance, Reactive Maintenance, and Predictive Maintenance. [12,11]

Reactive maintenance describes the process of operating equipment till it fails. This approach maximizes the total operating time but can lead to severe damages through increasing defects in other equipment or long, expensive downtime. *Preventive maintenance* exploits knowledge about the typical lifetime of the equipment. With this approach, healthy equipment will be replaced or repaired periodically before defects occur. This leads to minimal unscheduled downtimes at the risk of over-maintenance parts. [6] The more sophisticated approach of *Predictive maintenance* monitors the equipment's condition through different parameters and predicts the health based on intelligent AI-enabled algorithms, like machine learning. [13,6] It then predicts possible downtimes or defects and can trigger corrective action. This can maximize the equipment's operating hours while reducing repair costs and avoiding unscheduled downtime. [6] Therefore to offer condition-based monitoring Predictive Maintenance will be the focus of this research.

3. Methodology

To solve the research hypothesis and to derive an operational concept for the application of Predictive Maintenance concepts for DSOs we gathered the status quo and identified the constraints and requirements to implement such a new system into the operational structure. To allow the interview to proceed as openly and flexibly as possible in a structured manner, the semi-structured interview approach was used to interview grid controllers and foremen of DSOs of different sizes and different grid topologies (s. Table 1). Within the framework of this method, some questions are planned in advance and consolidated in an interview guideline based on a user story framework; however, the majority of the course of the conversation is kept open. Based on the guideline, the topic and the interview direction are specifically controlled. This design creates the basis for new insights that the interviewer had not previously considered and makes it possible to gather and structure existing insights [14]. The interviewed grid operators and relevant data regarding the grid topology are described in Table 1. The choice of partners ensured that we were able to gather different insights into the needs for grid operators of different sizes. We also interviewed business departments to record the initial business process landscape. The requirements and constraints were structured into user stories and built the base on which the operational model was developed.

Table 1: Overview of the interviewed grid operators and their respective grid topology (HV – high voltage; MV – medium voltage; LV – low voltage)

Grid operator	Habitants in area	Area served [km²]	Power line length [km]	Operated grid level
1	100.000 – 999.000	100 – 499	10.000 – 20.000	HV, MV, LV
2	<100.000	<100	<10.000	MV, LV,
3	100.000 – 999.000	<100	<10.000	MV, LV
4	>1.000.000	>1.000	>20.000	HV, MV, LV
5	>1.000.000	500 – 1.000	>20.000	HV, MV, LV
6	100.000 – 999.000	100 – 499	<10.000	HV, MV, LV
7	<100.000	<100	<10.000	MV, LV,
8	100.000 – 999.999	100 – 499	<10.000	HV, MV, LV

Generally, the purpose of operational concepts is to provide an overview of the activities utilizing one or more specific systems, or a group of related systems, in the organizational operational environment from the users' and operators' perspectives [15]. Therefore, we base the modelling of the operational concept on the common *Architecture of Integrated Information Systems (ARIS) Framework* and will detail the operational concept by describing the business process model, the IT-system landscape, and an information logistic model. Originally developed for the description and modelling of computer-based information systems, the ARIS-Framework has proven itself at the business concept level, i.e., at the semantic model level with (partially) formalized description languages, in the course of business process modelling, for solving organizational process problems, and for reducing complexity in the description of operational information systems [16]. It provides a structured approach for designing and implementing information systems that align with the overall goals and objectives of the organization. Therefore the framework describes in different layers the need for an organization view, function view, data view, process view, and product view.

[17] The context of the framework and the chosen models for the result documentation is outlined in Figure 1.

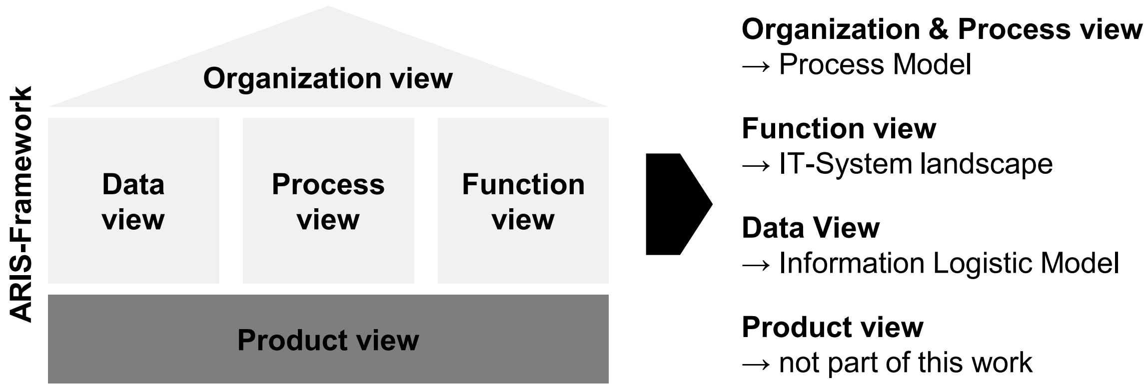

Figure 1 Context of the research methodology and models based on the ARIS-Framework based on [18]

The process and organizational view were modelled using the common *Business Process Model And Notation* in the 2nd version [19]. Furthermore, the description of the IT-system landscape describes the function view and is based on a typical UML-Class Diagram, which was abstracted for the applied use case [20]. For the data view, we model the information logistic concept using the *Information Logistics Notation (ILN)*, as illustrated by NIENKE et al. [21]. Because traditional interpretations of information logistics only model information as part of the flow of goods inside an organization [22]. We interpret information as an own logistical asset [23]. The ILN differentiates between stakeholders, database systems, and processing systems, representing objects that are characterized through an information sink on the left and an information source on the right side. Information flows are visualized through arrows between the objects. [21]

4. Operational Concept

The Operational Concept for the use of condition-monitoring based Predictive Maintenance strategies for medium-voltage switchgear is described based on the ARIS-Framework and will cover a Process Model (s. Chapter 4.1), a description of the IT-system landscape (s. Chapter 4.2) and an Information Logistics Model (s. Chapter 4.3).

4.1 Process Model

The process model for DSOs regarding Predictive Maintenance methods for switchgear equipment is visualized in Figure 4 in the Appendix of the paper. It describes the necessary actors, systems, and activities that must interact to offer Predictive Maintenance to DSOs. The model is designed to work as a business process visualization that helps employees to work with the system and as an instruction to implement it at DSOs. Therefore, it illustrates the organization and process view of the ARIS-Framework.

The relevant actors are the employees in the control centre and the installation technician. To interact in this system the process model introduces an Asset Management System (AMS), Geo-Information-System (GIS), and Machine-Learning-System (MLS). The model also interacts with external actors that are not part of the DSO’s organisation and provides different services.

The process is characterized by reducing the need for additional interaction with the foreman and triggering the maintenance activities condition based on demand. The industrial technician now can check and gather the necessary parts based on the information he receives from the Predictive Maintenance report. The need to first check the premises while doing preventive maintenance to order the correct parts now becomes obsolete. Furthermore, the process describes how the workflow can be structured to skip the need to digitize a paper-based maintenance protocol. Additionally, the process illustrates the possibility to include external service providers when the necessary workforce or specific data sources are not available.

4.2 IT-System landscape

The IT-system landscape as detailed in Figure 2 illustrates the different IT-systems, databases, functions, and interfaces as well as their interaction with each other to enable a condition-based maintenance application compatible with the proposed processes at DSOs. This represents the function view of the ARIS-Framework.

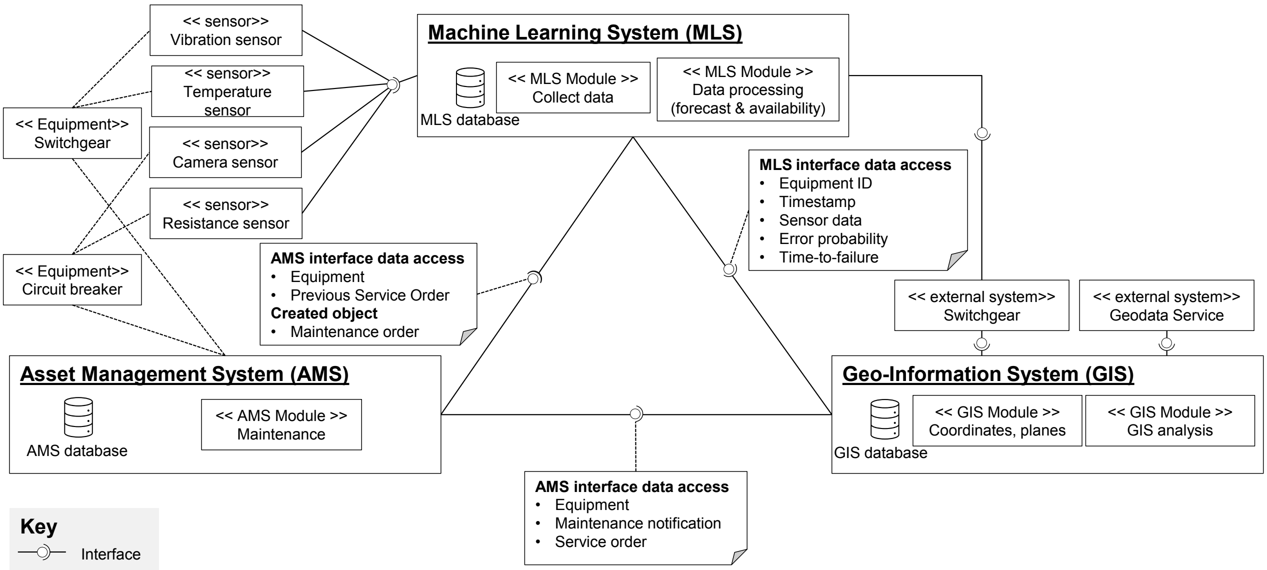

Figure 2 IT-system landscape and interfaces based on [24]

The AMS must share an interface with the MLS and contains the database that contains all the asset data regarding the circuit breaker and switchgear as well as the legacy maintenance function module which is based on a common Enterprise-Resource-Planning system architecture. Further an interface to the GIS is essential to share the notification and service orders. The MLS is the only system that is connected to the sensor hardware, which range from vibration, temperature, camera, and resistance sensors. Data will be collected in a dedicated database in the MLS, which includes the processing. To complete the architecture the MLS shares an interface with the GIS, which incorporates the necessary locations-based functions. While the AMS and GIS are mostly legacy systems that are already in use at DSOs the addition of the MLS makes the interfaces necessary to integrate it into the architecture. The proposed architecture can run on-premises or in the cloud but regulative restrictions regarding critical infrastructure must be evaluated in this case.

4.3 Information Logistic Model

The ILM in Figure 3 illustrates the information flow in the proposed system and the different information structures and dependencies and shows the data view of the ARIS-Framework. Therefore, this model shows how the connectivity in the whole application context is realized on the information layer.

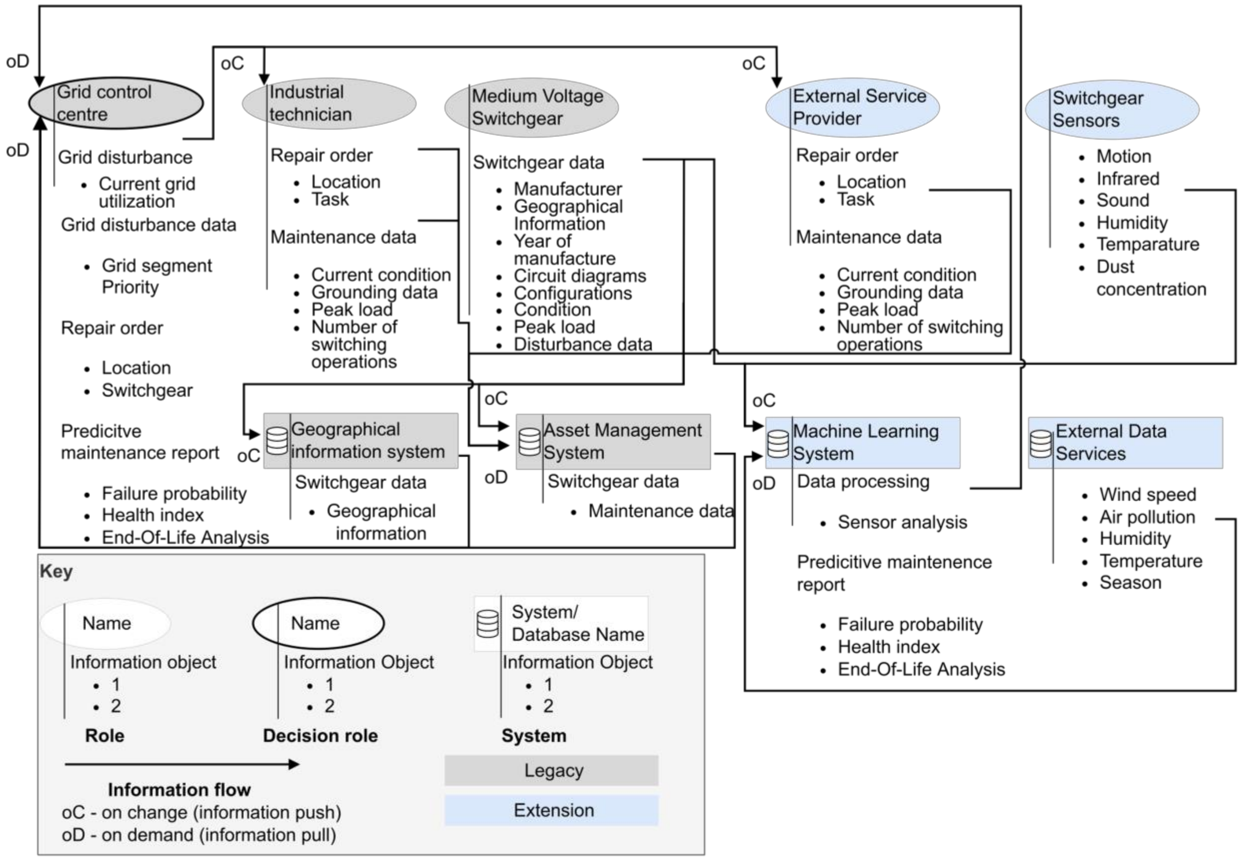

Figure 3 Information Logistics Model

As the decision role the Grid Control Centre needs to receive all information on demand. Other roles that must be considered while modelling the information logistics are the industrial technician, external service provider and the switchgear including the sensors, which push and pull information. The MLS takes a central role in pulling all information and pushing the results information to the Grid Control Centre. Overall, this model extends legacy systems at current DSOs and illustrates the extended information flow that derive from gathering, processing and evaluating data and information that come from the novel switchgear sensors and external sources.

5. Summary & Outlook

This paper presents an operational concept for the condition-based Predictive Maintenance of medium voltage switchgear specifically designed after the requirements of DSOs. It extends the current status quo of preventive maintenance strategies at DSOs and offers an operational concept for different abstraction layers in organizations. Therefore, this research gives DSOs an important indication and design guideline on how to implement AI-based maintenance strategies into their current asset management and how to structure the operations. Furthermore, this research creates further possibilities to research and create Service Systems and to lower cost for DSOs and enabling equipment resilience in the energy distribution grid. The operational concept offers further possibilities to be adapted for the use on other equipment or branches, which needs further evaluation. The implementation with the technical solution has to be evaluated as well as the practical relevance for DSOs in everyday operations.

Acknowledgments

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Appendix

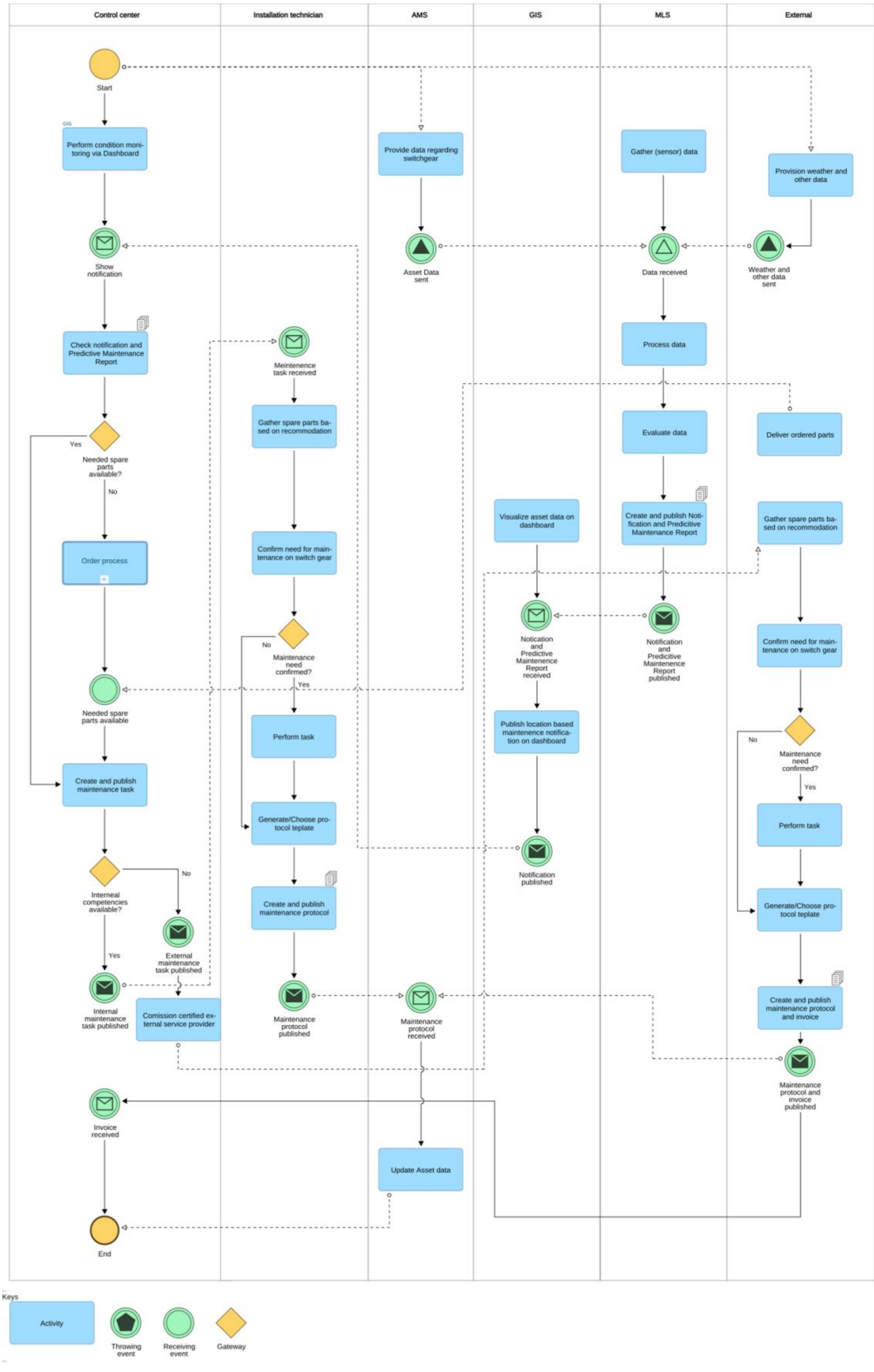

Figure 4 Overall Process Model

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Biography

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