FORMALIZED ENGINEERING OF THE INFORMATION EXCHANGE BETWEEN AUTOMATION AND PLANNING SYSTEMS

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Abstract

The article presents an approach on how to facilitate the engineering of data acquisition systems for SMEs. A semi-formal language is introduced, which is used by the management and maintenance staff of industrial companies in order to describe the data processing and routing from automation systems to planning systems. Thus information requirements are defined without ambiguities. The approach enables a parallel configuration of planning and automation systems, which leads to shorter introduction times for the data acquisition systems. The language is a result of a research project and publicly available.

Key words: *Advanced Planning and Scheduling, Enterprise Resource Planning, ERP, MES, SCADA*

1 INTRODUCTION

A detailed and exact planning of the production process is necessary for a profitable business of an enterprise. Especially small and medium sized enterprises (SME) have very challenging requirements on the flexibility of the production processes because they produce many different products in small lots for a variety of customers. Exceptions from the original production plan, e.g. caused by a temporary damage of a machine, have to be registered very fast in order to shift the production to other machines or to inform the customers about the scheduling delay in time.

Thus it is necessary to acquire the machine states online and to involve that information into the planning processes. Such a planning procedure is a basic building block for the concept of the Advanced Planning and Scheduling [see Stadtler, H.; Kilger, Ch. (2000) and Stadtler, H. (2005)]. Within SMEs there are often only two groups of staff involved into the application of APS. These groups are the production management and the technicians.

The production management uses an Enterprise Resource Planning System (ERP) as main utility, which is a software system for the management of energy, basic materials, personal staff and contracts. It is the task of the production management to identify the critical equipment and to define required data, which will play an important role for the planning of the production in context of APS. ERP systems mostly contain a representation of the structure of the production system. Thus they are the right tools to be used for the requirements specification for the data acquisition part usable for the application of the APS methodology.

Technicians are familiar with the automation systems, which control the production processes. The role 'technician' is called differently within different companies. Sometimes they are called electrical engineers in other cases they are simply the maintenance staff. External service providers play the role of the technicians within very small companies. The technicians are responsible for the data acquisition and computation of the data required by the production management within the context of APS. But often they lack the tools and opportunities to solve this task efficiently.

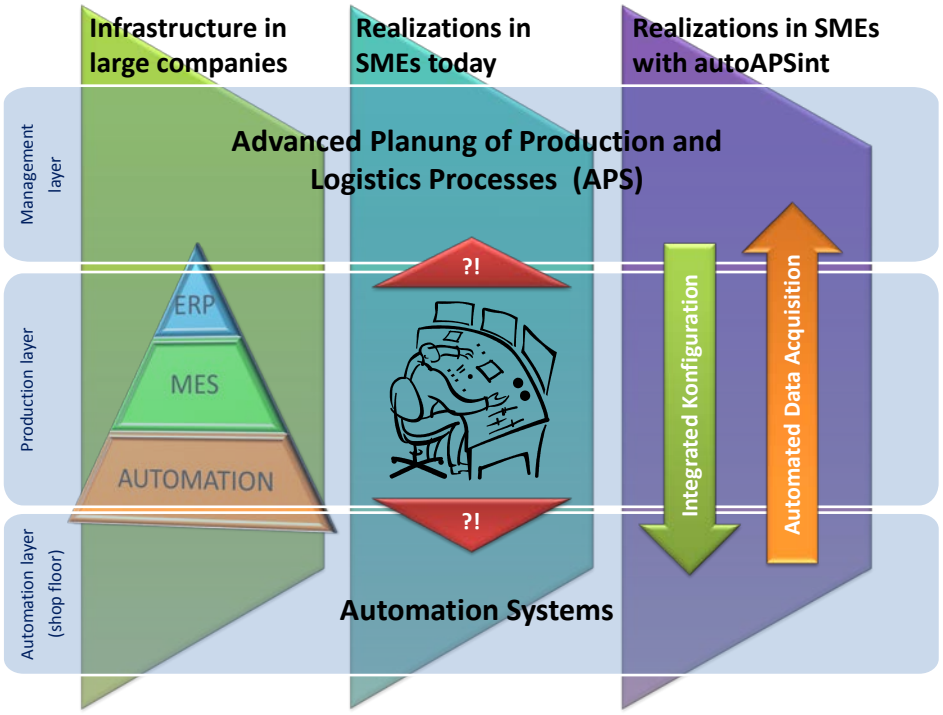


Fig. 1 Purpose of the autoAPSint project: efficient configuration of data acquisition systems for the application of APS within SMEs

There exists a variety of tools, which could be used by technicians to solve the task. Those tools are often summarized under the term Manufacturing Execution Systems (MES) [see ZVEI (2010) and Louis, Ph. (2009)] But an additional system layer would be introduced by using those systems. This would result in a need for more personal staff in order to program, configure and maintain the MES. That would be no option for SMEs, which often work under high cost pressure.

Several SMEs establish self-made solutions for the data acquisition in order to use the online information about machines for the APS purposes. Those solutions are often based on low level programming approaches, which are hard to maintain for SMEs. Commonly they provide only a limited set of information and are difficult to adapt onto changing machinery. If those solutions are developed by external service providers, then the competencies for the system adaptation are not in the hands of the producing SME.

A lean data acquisition system is presented in this article which could be used for the introduction of APS into SMEs. It has been developed within the research project autoAPSint (see Fig. 1) and has been evaluated prototypically. The approach avoids the high cost for the introduction and maintenance of an MES and provides a better flexibility than self-made solutions. A formal language for the dialog between production management and technician has been developed, which allows tool support within that dialog. The approach may be adapted by other companies, since this article describes the main ideas and the language specification is publicly available.

2 METHODOLOGY

The production management staff describes the requirements for the data acquisition currently by using text, images and tables, which are then sent to the technicians by using paper or electronic data formats. All specified data has to be translated manually by the technicians into a format, which is interpretable by computers and automation systems. That is an error-prone process and leads to much effort for the technicians in case of requirements changes.

The solution approach replaces the exchange of documents by the exchange of data sets. The syntax and semantics of those data sets is formally defined and thus data sets may be validated and then be interpreted and evaluated by the data acquisition and configuration systems.

The following workflow may be established from the point of view of the production management:

- The production management staff defines which online information is important from business point of view and which has to be acquired.
    - The production manager selects a part of the production system from its representation in the ERP system.
    - The production manager then assigns Key Performance Indicators (KPIs) to the selected production system part. Those KPIs may be chosen from a catalog, which contains the specifications of national or international standardization bodies or company internal specifications.
    - The production manager assigns aggregation functions to the KPIs for example geometric mean, maximum or minimum calculating functions.
    - The production manager assigns aggregation time intervals to the combination of KPIs and aggregation functions. Thus it becomes possible to define the needed information for example the 'mean value of the machine usage per hour' related to a specific machine resource.
- The production management sends the requirements list to the technicians by using new functionalities of the ERP system
- The production management monitors the fulfillment of the requirements. For that purpose the ERP system provides special visualizations (red/green icons) per specified combination of KPI, aggregation function and aggregation interval.
- The production management uses the online information from the machinery for the planning of the production processes. For that purpose additionally new functions are introduced in the ERP system.
- The following workflow may be established from the point of view of the technicians:
- The technician opens a software application for the management of the data acquisition. He or she gets some hints about new requirements coming from the production management.
- The technician assigns data acquisition functions to the KPIs. Those data acquisition functions are defined by a parameter set referencing addresses of the automation systems, and by a function body involving basic mathematical functions.
- The technician decides about the time interval for the acquisition of the KPI in order to compute sampling points for the aggregation processing later on.
- All those assignments are sent by the technician to the data acquisition system, which starts the collection of values, its storage and computation in order to make them available for the ERP system.

3 SYSTEM ARCHITECTURE

The system architecture used within the project consists of three layers (see Fig. 2). They are used to decouple the heterogeneous structure of the automation systems from the components providing the data acquisition logic. Those layers provide the necessary flexibility of the data acquisition system.

The functionality for the planning of the production process is realized by the ERP layer. A classical ERP system will be supplemented by an ErpConfigurator in scope of that system architecture. This is the tool, which is used by the production management to define the configuration according to the

workflow mentioned above. The ERP system has to communicate with the integration layer. For that purpose it uses an ErpAdapter. The communication technology OPC UA is used for the data exchange. It is a client/server technology, which is usable for the transmission of data as well as for alarms and events and for data histories. That technology additionally covers security aspects such as data encryption and the control off data access by using authorization and authentication principles [see e.g. IEC 62541 part 1-10 (2010-2014), Mahnke, W.; Leitner, St.-H.; Damm, M. (2009) and Jammes, F. ; de Oliveira, J.B. ; Colombo, A.W. (2010)].

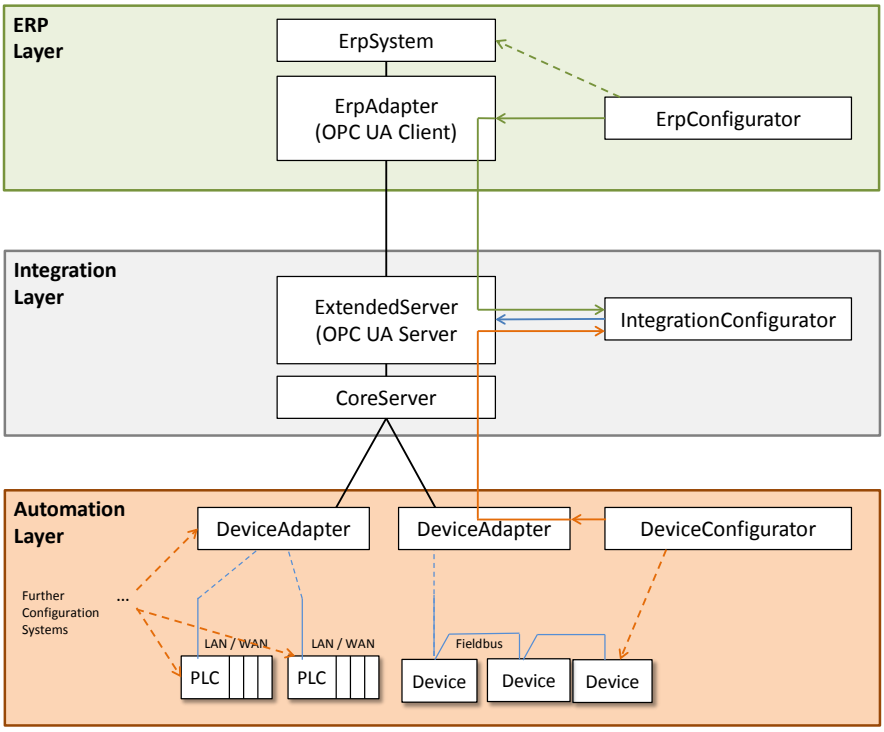


Fig. 2 System Architecture

The automation layer consists of devices like PLCs, sensors and motion control systems. Those devices realize the control of the production processes. They are source of information, which is necessary for an efficient production control. That information has to be transmitted to the integration layer, where it is processed and compressed. Special DeviceAdapters are introduced in order to establish that communication. Those adapters are small gateway solutions. The automation devices have to be programmed and configured in order to realize their tasks. For that purpose DeviceConfigurators are used, for example programming systems of PLCs. The DeviceConfigurators provide also the necessary information in order to configure the DeviceAdapters (e.g. variable lists and I/O lists).

A component for the storage of large data amounts is situated in the integration layer. It is called CoreServer within the context of the project. That database like system is supplemented by an ExtendedServer for the computation of the KPIs and the scheduling rules for the data acquisition. The APS requirements and configuration information of the DeviceAdapters may be used within the IntegrationConfigurator in order to create and change the configuration of the ExtendedServer. The technicians are the users of that IntegrationConfigurator. They produce the configuration of the ExtendedServer by using a graphical user interface which provides drag-and-drop facilities for the assignment of the KPIs to the computation rules as described in the workflow above.

4 FORMALIZED EXCHANGE OF CONFIGURATION INFORMATION

Well defined data formats may be used for the exchange of configuration information between production management and the technicians. Within the research project (autoAPSint, see www.autoapsint.ifak.eu) a proposal for such data format has been provided. XML [see W3C (2006)] has been chosen as basic data format. The specification of the configuration information to be exchanged has been done by using the description language XML schema [see W3C (2012a) and W3C (2012b)]. It is easily possible to check instance documents for completeness and correctness by using such a schema and a validating parser. There exist implementations of validating parsers in most programming languages.

Three schemas have been defined and published in scope of the project:

- KPICatalog Schema for the specification of Key Performance Indicators,
- AggFunctionCatalog Schema for the specification of aggregation functions,
- ApsConfiguration Schema for the specification of online data, which is necessary for APS from the view point of an ERP system.

It has been assumed that there are standardization bodies which define KPIs (for example [VDMA (2009)], which is a proposed input for the ISO standardization). But they define only the most common KPIs. It will be necessary to define company specific KPIs and other values to be monitored. Therefore a concept of KPI catalogs has been developed, which could be used by all of these parties (see Fig. 3). A setup of the system architecture described above may use multiple KPI catalogs, for example some standards-based and a company specific catalogs.

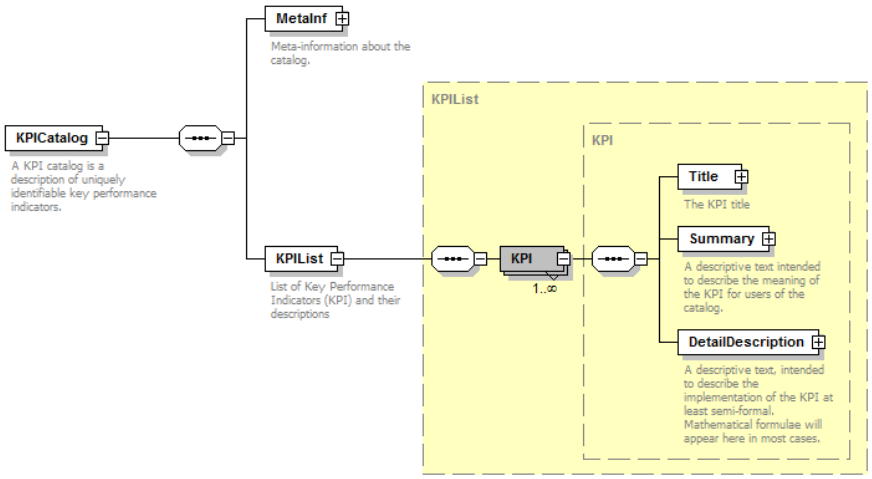


Fig. 3 Structure definition of a KPICatalog

The aggregation functions are handled like KPIs, which means that also the concept of catalogs has been applied for them. Complex APS scenarios may involve different aggregation function catalogs defined by standardization bodies or by the production management.

The ApsConfiguration will be defined by the production management for the current structure of the production plant. A set of KPIs, alarm variables and writable values may be assigned to each part of the production system. Each KPI references exactly one KPICatalog entry and one or more aggregation functions (see Fig. 4).

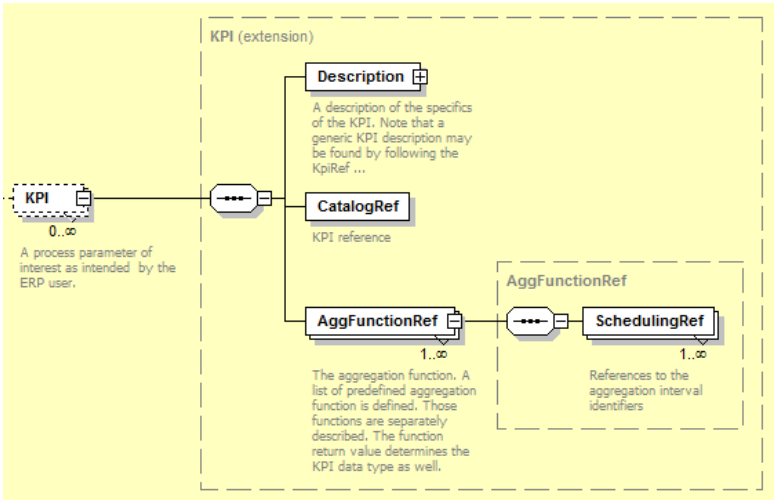


Fig. 4 Specification of a KPI within the APSConfiguration Scheme

The definition of scheduling rules is another important section of the ApsConfiguration. Such rules may be designed with high flexibility. Beside simpler rules like "every hour" there is a possibility to define more complicated rules like "every first day in a month" or "at the end of the quarter". That flexibility became possible because of using an open source software component called Quartz.net (see http://www.quartz-scheduler.net/).

All the three XML schemas presented here are publicly available on the Web site of the project. All elements are described with meaningful inline comments.

5 RESULTS

A high degree of efficiency could be reached at the introduction of a data acquisition system by using a prototypical setup of the system architecture described in section 3 and the approach of formalized configuration data exchange. Fig. 5 shows the graphical user interface of the production management staff. It is directly embedded into the ERP system. A form for the definition of a KPI is presented there. It becomes obvious that there is nearly nothing more necessary than selecting the resource node and to assign a KPI type of the catalog.

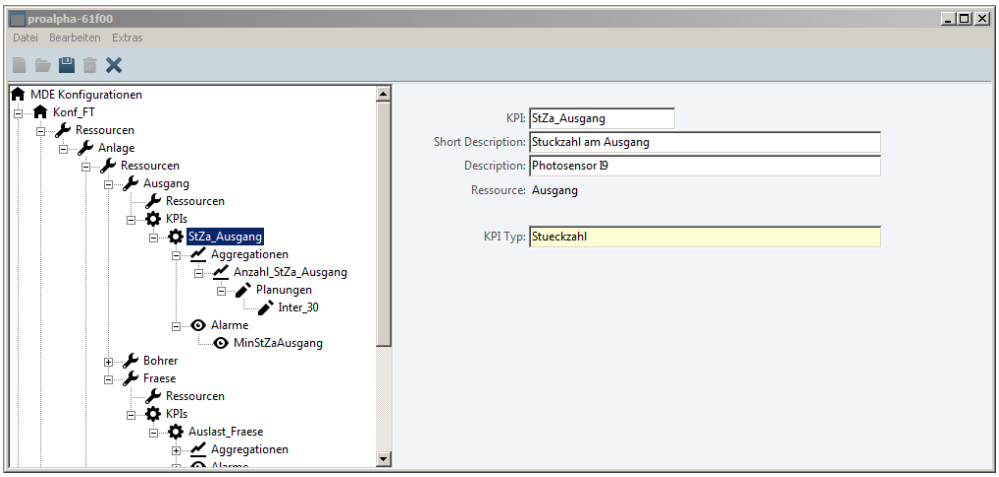


Fig. 5 Definition of a KPI in the ERP layer

Most programming systems for automation devices store and manage necessary variables in a kind of list. Those lists are often exportable as tables in a spreadsheet format. Fig. 6 shows a section of such an exported table. The syntax of the variables follows the IEC 61131-3 standard [IEC (2013)]. The example represents a PLC as automation device. It was possible to instantiate a special block within the PLC. That block is used to transfer the data by the field bus system MODBUS TCP [see Modbus Organization (2012) and Modbus Organization (2006)] from the automation device into the DeviceAdapter. The DeviceAdapter uses the exported table for extraction of the MODBUS register address. The DeviceAdapter may provide a list about the available process values to the CoreServer.

	A	B	C	D	E	F	G
1	Name	Path	Data Type	Logical Address	Comment	Hmi Visible	Hmi Accessible
2	PushButtonSlider1Front	Standard-Var	Bool	%I0.0		True	True
3	PushButtonSlider1Rear	Standard-Var	Bool	%I0.1		True	True
4	PushButtonSlider2Front	Standard-Var	Bool	%I0.2		True	True
5	PushButtonSlider2Rear	Standard-Var	Bool	%I0.3		True	True
6	PhotoTransistorSlider1	Standard-Var	Bool	%I0.4		True	True
7	PhotoTransistorMillingMachine	Standard-Var	Bool	%I0.5		True	True
8	PhotoTransistorLoadingStation	Standard-Var	Bool	%I0.6		True	True
9	PhotoTransistorDrillingMachine	Standard-Var	Bool	%I0.7		True	True
10	PhotoTransistorConveyorBeltSwap	Standard-Var	Bool	%I1.0		True	True
11	MotorSlider1Backward	Standard-Var	Bool	%Q0.0		True	True
12	MotorSlider1Forward	Standard-Var	Bool	%Q0.1		True	True
13	MotorSlider2Backward	Standard-Var	Bool	%Q0.2		True	True
14	MotorSlider2Forward	Standard-Var	Bool	%Q0.3		True	True
15	MotorConveyorBeltFeed	Standard-Var	Bool	%Q0.4		True	True
16	MotorConveyorBeltMillingMachine	Standard-Var	Bool	%Q0.5		True	True
17	MotorMillingMachine	Standard-Var	Bool	%Q0.6		True	True
18	MotorConveyorBeltDrillingMachine	Standard-Var	Bool	%Q0.7		True	True

Fig. 6 Table of PLC variables used for configuration of a DeviceAdapter

Additionally an IntegrationConfigurator has been prototypically implemented. The user interface is presented in Fig. 7. There are many predefined information parts usable by the technician. These are the ApsConfiguration and the catalogs (framed red on the left and middle part) and the information about all the available DeviceAdapters (framed green on the right side). But only a small part is used actively by the technician in order to configure the ExtendedServer (market blue in the lower part).

The technician starts the configuration of a KPI by selecting the relevant resource in the left part of the user interface. Then he selects the KPI, which has to be configured. Then he selects the process variable on the right side and drags it to the parameter list of an automation function, which is visible in the bottom part of the application. This newly created parameter gets automatically a parameter name (standard names are x1, x2, ...). Those parameter names may be used to define the function body in order to compute the KPI by using multiple process values and possibly to scale the result.

The configuration of the KPI may be send to the ExtendedServer after finishing the configuration process. Within the ExtendedServer that KPI configuration is processed automatically, which means that new database tables are created for the process values and the KPI and the scheduling rules are adapted and initialized. New OPC UA nodes are created additionally. That changed OPC UA model provides the opportunity for the ERP system to access the online data and value histories. The acquisition of raw values and the computation of the KPI and ist aggregated values is started automatically.

So the activities of the technicians may be technically summed up into two steps: (1) export of variables and (2) assignment of some process variables to the KPIs specified by the production management staff. The production manager gets exactly those data into the planning system, which has been specified, and has always the knowledge, which KPIs have been assigned to the shopfloor data. There is no longer a need to specify the APS requirements by using paper like documents.

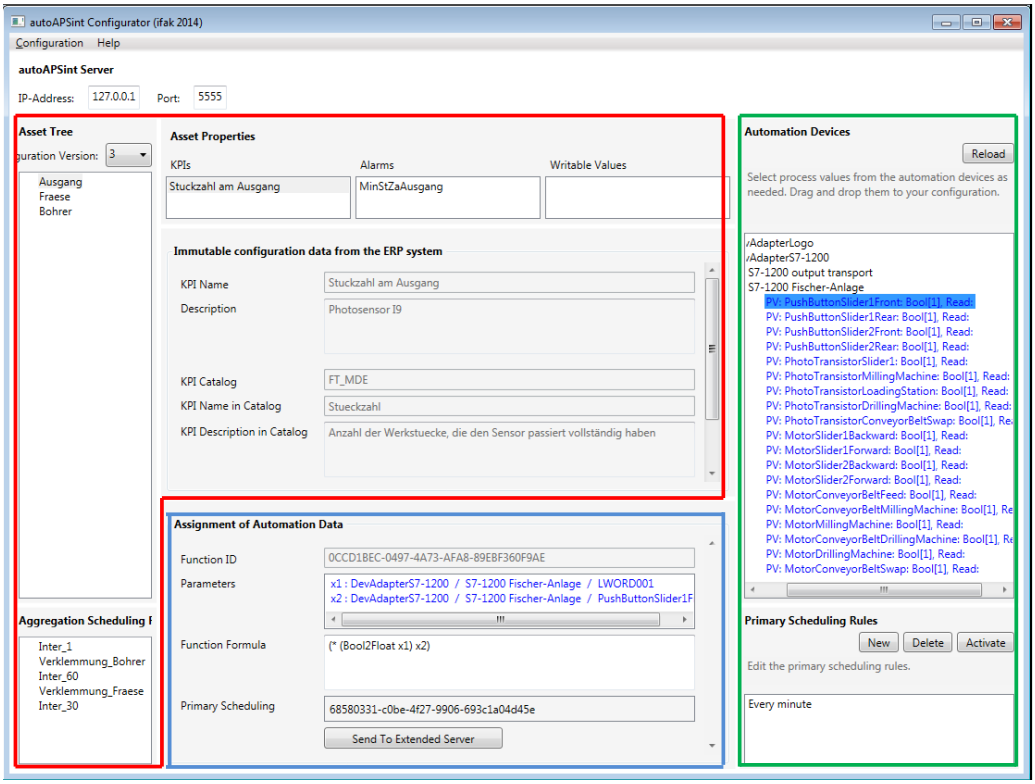


Fig. 7 IntegrationConfigurator user interface for the technicians

6 SUMMARY

This article describes an approach for an efficient configuration of data acquisition systems in order to support the methodology of Advanced Planning and Scheduling within SMEs. That becomes possible even under bad conditions, which often occur for SMEs, like the necessity of high production flexibility and a lack of well-educated personal staff for the purpose of data acquisition. The basic concept of the approach is a consequent formalization of the data exchange between the production management and the technicians. In addition a flexible and automated data acquisition system has been provided.

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