Towards an Intelligent Assistance System to Improve Environmental Compliance Continuity

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***Abstract*— Environmental regulations presuppose a complex set of corporate obligations to enforce legal compliance. The obligations may over-challenge companies in general but in particular manufacturing companies for many different reasons. This includes the inherent difficulties to recognize early signs for potential compliance violations, limited experience with effective actions to cope with potential violations, and also limited knowledge in the recovery from non-compliance situations. Based on the use of Internet-of-Things technologies for monitoring virtually anything in manufacturing companies, it is possible to develop a new generation of environmental compliance assistance systems that help companies to overcome these problems. The first results of investigations concerning this future system generation are described in this article. This includes an analysis of typical causes for non-compliance and a monitoring framework to deal with non-compliance sources. Furthermore, a conceptual framework for an intelligent compliance assistance system is proposed. The intelligent system provides users with compliance status information and action advice to cope with non-compliance. The intelligent capabilities are based on domain specific heuristic decision rules. The rule processing includes realtime analyses of context-specific background information. Through this and other features, the system can be specialized to the particular compliance concerns of individual companies.**

Keywords—environmental compliance management; assistance system; decision support; rule-based systems

I. Introduction

The enforcement of compliance with environmental regulations is a high-priority goal in all industries. Companies are frequently challenged by this goal because there exist many potential circumstances that may destroy an established situation in which all relevant regulations are satisfied (i.e. a positive compliance status) resulting into a non-compliance state. Therefore, we consider the concept of ‘compliance continuity’ which adds a temporal dimension and extends the above goal towards the goal to assure a positive environmental compliance status for as long as possible. This also includes the capability to rapidly recover from non-compliance through effective procedures. It is commonly expected that based on standards and recommendations such as EMAS [1] and ISO 14001 [2] effective management systems for environmental compliance continuity can be established. At the heart of these standards and recommendations is the requirement to systematically complete continuous compliance enforcement tasks by trained specialist. In manufacturing companies, in particular, the compliance specialist are required to permanently monitor anything of the manufacturing operations that may cause non-compliance such as the emission levels of noise, vibrations, odor, heat, waste air, and waste water. But also they should monitor the occurrence of human work errors, distortions in business processes, infrastructure problems, and equipment defects. Often, in the practice, only a minimalistic manual monitoring is possible due to resource constraints. Moreover, the complexity of non-compliance situations may over-challenge compliance managers’ capabilities for appropriate reactions and for fulfilling notification duties. Further problems may also arise from the difficulties to recognize in an early stage situations that may lead to compliance violations. These problems may result into a low compliance continuity.

In our research, the above described problem is addressed by the investigation of next generation compliance management systems for manufacturing companies. In this context, we especially study new opportunities for such assistance systems that result from the ongoing industry adoption of “Internet-of-Things” (IoT) technologies such as sensors, actuators, and intelligent embedded systems. This transition enables not only new unpreceded manufacturing options such as highly-individualized lot-size-one production orders. Also, for environmental compliance management, new possibilities will arise. This approach is exemplified in the article by the description of a novel assistance system concept. The system is intended to improve compliance continuity by providing context-depended help to compliance managers. The processing is performed on the basis of monitoring activities that are directed at a specified set of diverse non-compliance sources. For example, through the monitoring approach, human-lead work processes and manufacturing equipment components are continuously observed. The compliance status is both assessed for the current point in time and predicted for a near future time period. Furthermore, the system generates advice to effectively deal with non-compliance by counter-acting actions and to enforce predefined internal communication tasks and external reporting duties. The foundation of the system consists of a comprehensive set of domain-specific heuristic decision rules and corresponding algorithms for intelligent data analyses. Several of the evolving standards for the Industrie 4.0 vision [3] such as

OPC-UA [3] will severe as central enablers for a broad practical use of the assistance system.

In the following Section 2, compliance continuity as a company goal and typical non-compliance sources are described. A conceptual framework for monitoring non-compliance sources is contained in Section 3. Section 4 describes the proposed assistance system. Related work and conclusions are contained in Section 5 and 6, respectively.

II. COMPLIANCE CONTINUITY – GOALS AND TYPICAL NON-COMPLIANCE SOURCES

Compliance with environmental regulations has to be considered as a fragile binary status [4]. A positive compliance status is achieved when the entire set of compliance conditions is met while non-compliance means that one or more conditions fail. Compliance conditions are associated with anything contained in the manufacturing operations which we refer to by 'non-compliance source'. Non-compliance sources are directly or indirectly subject to environmental regulations due to their inherent direct or indirect influence on the company's interferences with the environment. One can observe different forms of this interference including pollution such as vibrations, noise, odor, waste air, waste heat, and waste water. It is a requirement for companies to be aware of their particular set of non-compliance sources and to do anything possible in order to avoid circumstances related to the non-compliance sources that lead into a non-compliance state [5]. Furthermore, it is expected from companies that through proper methods a (positive) compliance status is rapidly recovered when a non-compliance status emerges. By the notion of 'compliance continuity' we refer to these company obligations in a short form referring to the objective to permanently and robustly meet all relevant compliance conditions. In the following, three main categories of non-compliance sources are described. Table 1 contains several sample cases of non-compliance related to the three non-compliance source.

Work processes. In general, work processes bear the likelihood of human-work failures. For more than a decade, methods that target to improve the reliability of operational processes in manufacturing companies have been successfully applied. Examples are the Poka Yoke method [6] and the Six Sigma method [7]. In general, these methods attempt to minimize the occurrence of human work errors and/or to mitigate their impact on process throughput, product quality, service quality, and cost. The methods focus on work errors of individuals that are caused by the so-called 'human factors'. This includes tiredness, illness, fatigue, and mental problems that may lead to a wrong perception of a given work situation or a perception bias. Some of the methods also consider work errors of groups of individuals caused by known phenomena of group work and of Groupthink Effects [8]. A considerable number of reports about the successful use of these methods can be found in the literature. Nevertheless, it is only an illusion to assume that through these methods organizations can be established, that are completely free of any human work errors. Even with the most sophisticated error defense measures, still human-work failures will happen once in a while since the happening of errors is intrinsic to human work.

Compliance management tasks involve many human-lead activities [4]. Sample activities are the active monitoring of regulation announcements, the judgement of the relevance of regulations and revisions, the creation and selection of measure alternatives, and the implementation of measures. Some of these activities are completed by individuals alone and some of them are completed by several individuals together in a group work approach [9]. Also, the manufacturing operations tasks contain, even in companies with a high degree of automation, human-lead activities such as the preparation of production machines, material transport, shop floor control tasks, quality checks, and machine cleaning. When errors occur in these human-performed activities – both in compliance management tasks and operations management tasks - then it is possible that the consequences of the errors include non-compliance or a risk that the company will move into non-compliance at a future time point. Table 1 contains several examples of human work failures due to human factors and/or problems inherent to group work. For each of these examples, there is a considerable potential that a non-compliance status is caused.

Physical infrastructure and manufacturing equipment. Manufacturing companies normally require a complex facility infrastructure. The typical constituent elements of this infrastructure include, first of all, plant buildings with, of course, supply of energy, water, air, heating, fire protection equipment and data communication facilities. As demanded by respective laws, the infrastructure needs also to include special environmental protection facilities such as exhausts, chimneys for gaseous emissions, waste water treatment plants, and waste air cleaning facilities. Further sample infrastructure elements are warehouses and inbound logistics facilities such as tubes, pipes, bands, and escalators for transportation of material and persons. The facility infrastructure is complemented by the machinery equipment including machines, robots, production cells, devices, tray ovens, coating pans, fluid bed dryers, and tools. Furthermore, also equipment needs to be considered that targets factory automation, monitoring, and control such as Programmable Logic Controllers (PLC), SCADA devices, middleware like OPC servers, and special software systems like Manufacturing Execution Systems (MES), Facility Management Systems, and Control Stands. Today, these components are usually interconnected within a common industrial communication network. In addition to that, existing occupational safety regulations mandate to consider precautionary measures to prevent threats and work accidents. These measures include safety fences in the shop floor, safety training of workers, and the use of safety equipment and safety clothing.

It is a well-known general fact that, over the usage time, the technical infrastructure and machinery equipment is subject to a shrinking reliability and an increasing failure rate. The reasons for this include use (incorrect use, over-use), inherent material aging, quality problems, construction errors, and hardware/software errors. Also, the influences from other infrastructure components and the environment including heat, vibrations, humidity, magnetic/electro smoke, dust, and harmful steam can lead to reliability problems.

TABLE I. SAMPLE NON-COMPLIANCE SCENARIOS FOR DIFFERENT NON-COMPLIANCE SOURCES

Work Processes
measure effectiveness check is not completed until the given deadline
formal instruction of workers defined as enforcement measure is not completed until the given deadline
group decision process about enforcement measure is behind schedule
measure effectiveness check determines that a revision of an installed enforcement measure is required, the need for this revision is not addressed
hazardous material is unloaded at an inappropriate storage location
a worker performs a certain production step at a manufacturing machine but the necessary safety instruction by a supervisor is missing
machine configuration error is made so that too much cooling liquid is used by the machine
hazardous waste is put into wrong waste disposal container
waste water filter is not correctly replaced resulting into too heavily polluted waste water which is lead into a river
quality check of raw material from supplier is performed improperly; raw material with high degree of impurities is used which leads to significant odor creation
Physical Infrastructure and Manufacturing Equipment
pipeline defect causing loss of hazardous liquid
Software bug causing the use of wrong raw material for production; production step yields waste air with above the permitted limit of pollution
Valve problem in evacuation pipe for cooling liquid causing spill
Software bug in control program of a soldering oven causes bad odor
(undetected) overuse of a punching machine causes noise emission above a permitted upper limit
Tank leakage causing spill of chemical substance into ground soil
Defect in plant to destroy emission from tray ovens which causes gaseous emissions above a permitted level
Leakiness in roof of a warehouse building causing a dangerous chemical reaction of stored material during rain fall
Exceptional External Events
Extreme rain fall causing a capacity overload of a wastewater treatment plant; waste water with above permitted pollution limit is lead into a natural river
Extreme deep temperature causing a burst of a pipeline; burst results into spill of hazardous liquid
Flash stroke causes power outage; recovery into emergency operation with emergency power generator requires too much time leading into emission of uncleaned waste air
Period with extreme hot temperature causes toxic air in factory halls due to evaporation of liquids used in production such as oils and cooling liquids
Land slide damaging a warehouse with hazardous chemicals

Reliability improvements can be achieved through reliability engineering methods and risk management methods that especially address hard to predict events such as hardware failures, network transmission errors, data corruption errors, sensor errors, and measurement errors. Also, it has been demonstrated that reliability improvements can be expected from proactive maintenance approaches [10]. However, even with most advanced methods, there will always be a certain residual risk for the occurrence of defects, malfunctions, and breakdowns of items of the infrastructure and machinery equipment, respectively. Such occurrences can cause hazardous situations for the people (i.e. work accidents), production problems (quality problems, production rejects), but in particular also problems for the environment. When appropriate protection measures are missing or when they fail to defeat a given positive compliance status, all kinds of violations of environmental regulations can happen (e.g. leakages, spills, illegal emission of odor, noise, waste air, waste water, and air pollution). The failing may lead with some time delay and not immediately to a non-compliance status. Table I contains several examples of technical problems that may cause a non-compliance status.

Exceptional external events. There always have been exceptional external events that companies have to cope with. This includes extreme weather conditions such as thunder storms, heavy snow fall, wind chills, hail, dryness, flooding, and landslides. Other examples of exceptional events are massive infrastructure outages and breakdowns (e.g. power grid outages, water supply outages) and high magnitude accidents (e.g. railway/airplane crashes, ship accidents). Obviously, such events may also have effects for manufacturing plants and their environmental compliance situations such as exemplified in the sample scenarios in the bottom part of Table I. Therefore, in today's factory planning processes, external events are taken into consideration in order to determine proper safety measures. Examples for safety measures include emergency power generators, disaster recovery procedures and backup mechanisms for the IT, fire and explosion protection facilities, emergency plans, safety valves in pipelines, and flood protection equipment.

III. FRAMEWORK FOR MONITORING NON-COMPLIANCE SOURCES

Obviously, in order to establish and maintain compliance continuity, one needs to address the relevant set of non-compliance sources. That is, one first needs to become aware of and then define the relevant non-compliance sources. Following that, through a corresponding evaluation (e.g. a specialized risk analysis) it needs to be defined if at all and what kind of monitoring activities are to be carried out. The principles and methods for these tasks are described elsewhere. The focus of the framework that is described in the following is on an automation of monitoring activities and the fusion/integration of the monitoring data by the definition of abstractions that are depicted in Figure 1. The abstractions model physical monitoring devices and the monitoring data, respectively. The abstractions have been specialized to the processing needs of the compliance assistance system described late.

Logical Compliance Management Unit (LCMU). The 'Logical Compliance Management Unit' defines the scope of the organization that the assistance system deals with. For example, one may define a single manufacturing plant at one location, multiple plants that are located together within a common region, or all plants of a global manufacturing company to be the LCMU. The definition of a LCMU includes the definition of the set of relevant areas of legal regulations. The number of required monitoring activities, mainly depends on the physical size that is covered by the LCMU, the particular set of relevant environmental regulations, and the (risk) attitude of the company. Note that all of the following concepts are abstractions of items that characterize a particular company. After a corresponding LCMU has been specified for the company, these concepts are to be defined as logical constituents of the LCMU.

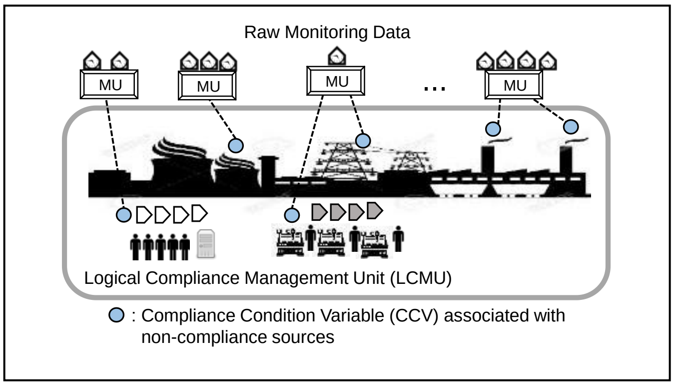

Figure 1. The Monitoring Framework.

Monitoring Unit (MU). A 'Monitoring Unit' refers to a particular device or system that is equipped with monitoring capabilities. MUs observe and generate monitoring data about non-compliance sources. In order to support diverse sets of non-compliance sources, monitoring capabilities in a broad sense are considered. Table II gives an overview of typical types of MUs that are considered. The data are obtained by MUs through a continuous measurement or assessment of properties of non-compliance sources.

TABLE II. EXAMPLES OF MONITORING UNITS

Type of Monitoring Unit
Sensors, pollution measurement devices, thermometers, gas detectors, and other mobile or stationary measuring apparatus which provide capabilities to monitor pollution levels of anything that is exposed by manufacturing operations into the environment such as waste water, waste air, waste heat, noise, magnetic smog, odor, vibrations.
Hardware and software systems and components of the so-called 'Information Pyramid of Automation' [18] that monitor and control the operations state and conditions of the manufacturing equipment. Examples include Manufacturing Execution Systems (MES), Process Information Management Systems (PIMS), Condition Monitoring Applications, SCADA systems, PLCs of production machines, OPC servers and special measuring apparatus for the detection of defects and inspection needs such as pressure gauges.
Traditional so-called process aware enterprise computing systems with integrated functionality to track and trace human lead and/or machine lead work processes and actions. Examples of such systems are ERP systems, Supply Chain Management Systems, Warehouse Management Systems, Production Management Systems, Facility Management Systems, and standalone workflow management systems.
Traditional business application systems with integrated domain-specific analytical functionalities. Examples are EHS systems and plant maintenance systems. Also, general analytical information systems are considered as Monitoring Units.

Compliance Condition Variable (CCV). A 'Compliance Condition Variable' is a dynamic property of a non-compliance source which is relevant for the compliance status. Table III contains the different categories of CCVs that are considered. The property value is monitored by a corresponding Monitoring Unit. In principle, it is desired that the values of CCVs are kept in their predefined 'normal ranges'. Multiple of such normal ranges can exist for a given CCV targeting different applications such as fault detection, predictive maintenance, resource planning, and environmental compliance management.

TABLE III. EXAMPLES OF COMPLIANCE CONDITION VARIABLES

Category of CCV
CCVs that indicate measured pollution levels of anything from manufacturing operations that is exposed into the environment.
CCVs that measure physical conditions of machines and plant components.
CCVs that are directed at executing instances of work processes at the operational level. In particular, process instances are targeted that have to fulfill defined deadlines and outcome constraints for the expected process results (i.e. post-conditions to be fulfilled upon activity completion).
Traditional business application systems with integrated domain-specific analytical functionalities. Examples are EHS systems and plant maintenance systems. Also general analytical information systems are considered as Mus which companies use for specific analyses of operational data.

IV. RULE-BASED ASSISTANCE SYSTEM

Our research strives to investigate a knowledge-based assistance system approach for environmental compliance managers. The main principles of the intended system can be described as follows. i) On the basis of the previously described monitoring framework, the system obtains monitoring data about the relevant non-compliance sources. This includes in particular all kinds of emissions produced by the manufacturing operations (e.g. noise, vibrations, air pollution, waste water), human lead work processes that are relevant for environmental compliance, and equipment failures and defects. ii) The system analyses the monitoring data and also other context-specific background data in order to assess the current compliance status and to predict the compliance status for a near future time period (e.g. next ten days). Also, the system derives situation-specific user advice which includes counter acting measures in order to cope with conditional compliance or non-compliance.

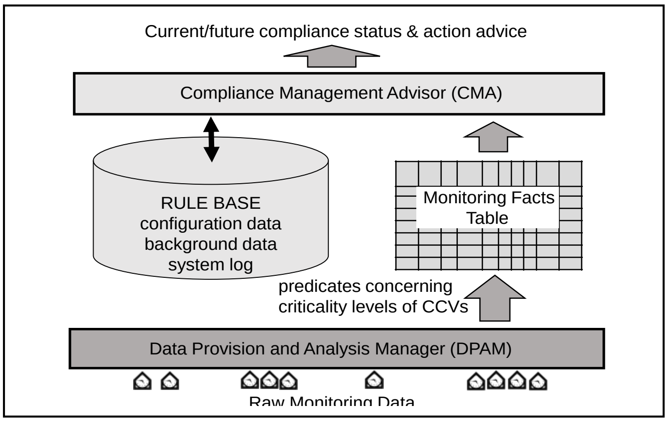

Figure 2. Conceptual Architecture of Assistance System.

The conceptual architecture of the system is depicted in Figure 2. The two main processing components are referred by 'Data Provision and Analysis Manager (DPAM)' and 'Compliance Management Advisor (CMA)'. The system's central database contains a rule base, configuration data, background data of relevance for compliance management, and a continuously updated system operation log. Among others, the configuration data refer to the abstractions of the monitoring framework such as the installed MUs and the set of CCVs. The context specific data constitutes an important part of the system, because it is utilized by the CMA in order to address company-specific individual concerns within the computation of the compliance status.

The DPAM acts as data interchange and data integration engine which performs data processing and data analysis cycles. An illustration of the principle processing steps of each cycle is shown in Figure 3. Per cycle, the raw CCV parameter values are obtained from the set of installed MUs. In Figure 3, three corresponding sample values are given that refer to properties of waste air measured by a sensor: temperature of 47 degree Celsius, 56 µg SO_2 share, 14 µg NO_x share. For every CCV value, predefined condition checks are performed. Note that the predefined checks needs to be specialized to the interfaces, data formats, and measurement scales of the corresponding monitoring devices. Through these checks, for the current point in time, the level of conformance of the non-compliance source with respect to predefined baseline levels (e.g., maximum permitted levels of waste air properties concerning temperature, SO_2 share, NO_x share) is computed in the form of predicates. From another point of view, one may regard the derived conformance levels as criticality levels of non-compliance sources, too. The predicates state the truth value of conditions that concern non-compliance sources and that are indicated by CCVs. The mapping of the heterogeneous raw monitoring data into predicates can be viewed as a normalization process that yields data about non-compliances sources in a homogeneous format. The normalization approach provides the advantage that the predicates establish abstractions from the specific details of Monitoring Units such as data formats, scales, and units of measure. Thus, it is possible to focus on the predicates in the further processing steps.

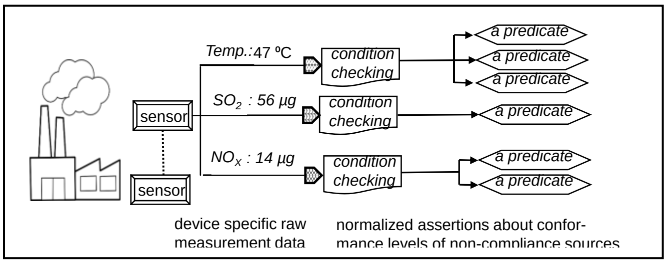

Figure 3. Obtaining predicates from raw monitoring data.

A logical fact table, referred to by 'Monitoring Facts Table (MFT)', serves as media for the frequent data interchange between the DPAM and the CMA. The DPAM writes the obtained predicates into the MFT table and overwrites the predicates of the previous cycle. The CMA performs two "intelligence" analysis steps. In these steps, the current MFT content and possibly context-specific background data are evaluated. The assessment analysis of Step 1 yields the current compliance status while the prediction analysis of Step 2 provides the near future compliance status. In any of these two steps, the CMA may also derive advice for the users such as actions to effectively handle and mitigate non-compliance and conditional compliance, respectively.

A. Rule Processing and Structure of Rules

A rule base serves as foundation for the system's assistance capabilities that require intelligent context-sensitive analyses. The rule base contains domain-specific heuristic decision rules to assess and predict the compliance state and to generate advice. The rule processing mechanism of the CMA checks the rule base for rules to be applied according to the current set of predicates (i.e. compliance conformance levels) as stored in the MFT table. In principle, executing matching rules yield the compliance status information and action advice. When there exist several matching rules, then the CMA's conflict resolution mechanism chooses the most appropriate rule for execution. If no matching rule is found, then a general advice for the user is considered.

Our research does not aim at the unrealistic goal to address all potentially possible situations in which measured values of non-compliance sources need attention by compliance managers. Instead, it is intended to focus on situations that either are highly likely to occur or that are of high importance.

As illustrated in Figure 4, a decision rule consist of a condition part, a compliance status determination part, and an action advice part. The condition part specifies predicates that, as described above, indicate the conformance level – or criticality levels - of non-compliance sources. The rule's set of predicates may concern one or more CCV variables that originate from one or more MUs. Furthermore, the condition part also consists of an optional set of context-specific conditions. These conditions are evaluated at runtime through analytical queries against background data contained in the central database.

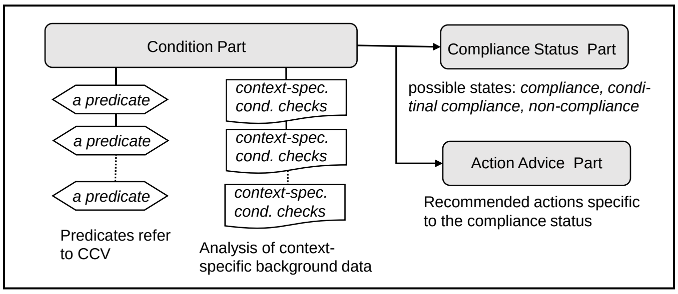

Figure 4. Structure of heuristic decision rules.

The compliance status determination part specifies the compliance status being assessed or predicted by the rules in the form of either one of the three categorical values 'compliance' (cp), 'conditional compliance' (cc), or 'non-compliance' (nc).

In the action advice part of the rule, actions are assigned. Sample actions are actions to prevent and/or mitigate non-compliance, investigation actions, escalation management actions, company internal information management actions, and actions required to comply with legal reporting duties.

In principle, matching rules are identified in two steps in which the condition part of the rules is evaluated. First the set of predicates contained in the MFT table are compared to the rules in order to determine the rules with matching predicates. Then, in a second step the optional context-specific condition checks are completed. A rule is considered as a matching rule when the entire condition part evaluates to true.

Typically, the rule base consists of many subsets of rules. Every rule subset is oriented at a particular non-compliance source that the system is intended to address. Therefore, the rules of a rule subset refer to the same set of CCVs and, thus, same set of predicates, too. Logically, differences in the truth values are specified in the rules in order to check the actual level of conformance with compliance regulations and to result a corresponding compliance status value.

In the following, the principles of the heuristic decision rules are exemplified by describing two sample rule subsets contained in Table IV and V. Some of the rules assess the compliance status for the current time point (signified in the column heading by "Ass.") while others predict the compliance status for a near future time interval (column heading "Pred.").

The rules in Table IV are directed at the enforcement of air pollution regulations for which three temperature levels of waste air are considered. The three temperature levels are obtained by the system through three predefined CCVs which are denoted by Term1, Term2, and Term3. In the MFT table, the levels are expressed in the form of abstract criticality indicators that result from a comparison of the raw monitoring data with specified thresholds ('warning level', 'permitted level').

Table V contains compliance enforcement rules that are directed at group decisions about compliance enforcement measures for occupational safety regulations. When such group decisions are not completed on time then the implementation of the measure is likely to become overdue. As a result, the intended compliance enforcing effect will miss a given deadline and, thus, result into non-compliance. Therefore, the monitoring data are analyzed with respect to temporal conditions of the respective ongoing group decision process. It is assumed that the decision process instance is completed on the basis of a work flow management system from which respective monitoring data is obtained. The CCV denoted by Wf_full_1 refers to the particular process instance which may impact the compliance status when it is not completed on time.

TABLE IV. SAMPLE RULES TO ENFORCE AIR POLLUTION REGULATIONS.

CCV	**Criticality according to MFT**	**Rules**			
		Ass.	Ass.	Pred.	Pred.
Term1	Over permitted level	Y	N	N	N
	Over warning level	Y	Y	Y	Y
Term2	Over permitted level	-	-	-	N
	Over warning level	-	-	-	Y
Term3	Over permitted level	-	-	-	N
	Over warning level	-	-	-	Y
Background Condition					
previous compliance status "nc"		-	N	Y	-
Compliance status		nc	cp	cc	cc
Actions					
Create high priority service ticket		X	-	X	X
Contact production planner for adaptation of production schedule		X	-	X	-
Check production schedule for next weeks and attempt to balance out/get rid of peaks		-	X	-	-

TABLE V. SAMPLE RULES TO ENFORCE OCCUPATIONAL SAFETY REGULATIONS.

CCV	**Criticality according to MFT**	**Rules**			
		Ass.	Ass.	Pred.	Pred.
Wf_full_1	Fulfillment significantly overdue	N	Y	N	N
	Fulfillment slightly overdue	Y	Y	Y	Y
Background Condition					
Similar group decisions often caused delayed measure implementations		-	N	Y	Y
Is high priority measure		N	N	N	Y
Compliance status		cp	cc	cc	nc
Actions					
Contact decision owner and discuss options to speed up		X	X	X	X
Contact project manager and discuss options to adjust		-	X	X	X
Schedule and conduct escalation meeting		-	X	-	X

B. Contextualization Mechanism of Rule Processing

One may determine the compliance status purely based on the monitoring data as addressed in our framework, i.e. on the basis of conditions indicated by CCV variables. However, we assume that a better level of precision can be achieved by adding insights from realtime analyses of context-specific background data. On the one hand this extension increases the complexity of the processing efforts. On the other side, it can be expected that the more extensive and context-specific insights will lead to more accurate assessments and predictions of the compliance status and also to more accurate action advice. That is why a contextualization approach is considered. The approach allows rules to include optional runtime queries against background data available in the database. Examples of background data are workflow models, historic indicator data, historic maintenance data, historic measurement data, statistical data including workflow statistics, failure statistics, inspection and maintenance schedules, and the system log which contains earlier processing results of the DPAM and CMA. In principle, the analyses are performed based on predefined analytical queries. The queries are to be specified at system configuration time and when the rule base is extended, respectively.

C. Initialization and Evolution of the Rule Base

As argued above, the rule base is intended to contain rules for situations that are highly likely to occur and also for situations that are of high importance. It is assumed that with the involvement of domain experts a proper generic set of rule templates can be developed. On the basis of the generic initial rules, one needs to create a set of specialized rules that correspond to the characteristics of the targeted application scenario. This specialization task includes, in particular, the development of database queries. As described above, these queries are intended to enrich the generic rules by context-specific condition checks.

Obviously, while the system is being used, compliance management situations will emerge. It is expected that many of these situations involve the system as an aid for helpful compliance status information and situation-specific action advice. Any of these compliance management situations has to be viewed as a source for the acquisition of additional knowledge about what circumstances may arise from existing non-compliance sources and how they should be addressed. A continuous enrichment of the assistance system by any recently discovered new knowledge through a corresponding evolution of the rule base (i.e. insertion of new decision rules) will improve the power of the assistance system. Therefore, it is intended that the system will support a flexible and user-friendly set of functionality to revise existing rules and to add new rules.

V. RELATED WORK

Two large projects that have been launched in the context of Industrie 4.0 research programs are also targeting the development of novel assistance systems for intelligent production. In the FEE project [11], it is looked at the problem that in today's processing plants the operators' experience with process dynamics is often limited which may result into information overload in critical situations. The project targets to develop new real-time big data methods to analyze heterogeneous mass data from plants including engineering data, laboratory measurement data, and plant operations data. The analyses are directed at the early stage detection of critical situations in the plant. Also assistance functions are developed in order to support operators in decision making during critical situations. The ideas of the FEE project seem to be especially suitable for big manufacturing plants of the process industry. The security concerns for such plants are often tremendous especially in the gas and oil industry and in the chemical and pharmaceutical industry. Therefore, often complex process monitoring and control systems are used in respective companies. For example, it is reported that in the FEE case study data from 66.000 sensors are gathered. Even though there exist some obvious similarities between our system approach and the FEE project, we are targeting a more simplistic approach for smaller companies of the discrete manufacturing industry such as automotive and car manufacturers. In contrast to the FEE project, in our approach also monitoring data from legacy process-aware application systems are considered. The APPsist project [12] targets a holistic approach for human-machine interaction in production through the development of novel multimedia assistance systems. Based on automatic adaptation capabilities, the targeted assistance systems are able to address the specific needs of the users in situations such as installation of new machines, defect handling, and preventive maintenance. The assistance capabilities built on the use of Artificial Intelligence technologies and they are offered as cloud-based services. The cloud is integrated with all relevant system layers including the machine and automation layer and the planning and controlling layer where ERP systems are typically used.

A comprehensive introduction of modelling and control for intelligent industrial systems is given in [13]. The guiding book, among others, covers the use of multi-sensor data, fault detection and fault diagnosis approaches and the use of swarm intelligence and machine learning for industrial problems. A new fault handling approach in Industrie 4.0 automated production systems especially targeting restart and self-configuration capabilities is proposed in [14].

In [15] an expert advisory system is described that also combines a rule-based system with a subsystem to handle input data (symptoms for diseases of Chili plants) for which no rule can be found in the rule base. The Artificial Bee Colony algorithm serves as foundation for the subsystem to generate a diagnosis of the particular disease and to propose a corresponding cure. For our approach, a more complex rule structure is defined in which a set of actions is associated with each rule as compared to only a single proposal of a cure and disease in the referred expert system.

Various rule-based approaches addressing process monitoring and failure detection have been proposed. The REALM approach developed by IBM Research [16] is especially directed at compliance automation. Regulations are first expressed based on logical models and then automatically mapped into processible rules. In the literature several projects are described that target the monitoring of workflows in order to detect compliance violations [17] [18]. An overview of the work in this field is given in [19]. However, to our knowledge, dynamic predictions of potential compliance violations of ongoing workflows has not been addressed before.

VI. CONCLUSIONS

Major considerations for intelligent environmental compliance assistance systems and a corresponding novel system concept have been described. It is expected that the compliance status information and advice provided by the system to compliance managers will improve corporate compliance continuity and, henceforth, save the company from consequences of compliance violations. The assistance power of the system, among others, is dependent on the rules which constitute machine processable knowledge of domain experts. An ongoing project targets to systematically acquire corresponding domain knowledge by interviews with environmental managers and by a thorough literature study. This includes in particular case descriptions and advisory documents provided by international environmental and safety advisory commissions and agencies.

It is a prerequisite of the proposed assistance system that one may easily establish an effective integration of the system with a heterogeneous set of monitoring components. At a first glance, this prerequisite can be viewed as a significant obstacle for the practical use of the system. However, it can be assumed that the large number of ongoing development and standardization initiatives for enabling the Industrie 4.0 vision [20] will significantly ease the system integration task. Especially, from the vendors' participation in these initiatives, it can be expected that the future 'all-connected' manufacturing system landscape will support a plug-and-play style of system integration.

A future system refinement step targets to make use of a machine learning mechanism to compute context-specific responses when no matching rule is found. We intend to evaluate Artificial Intelligence techniques that have been successfully applied for similar tasks. This will especially include an evaluation of meta-heuristic approaches such as decision tree learning and decision list learning.

The assistance system is currently being developed based on an existing compliance management research prototype [not disclosed in submitted version]. The ECO-Factory learning lab which is a joint initiative of a university with local manufacturing companies and software vendors will be used as a first testbed for the evaluation and later refinement of our framework [not disclosed in submitted version].

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