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Innovative end-to-end Management of Dynamic Manufacturing Networks

"Innovative end-to-end management of Dynamic Manufacturing Networks"

Deliverable D2.2.3

IMAGINE and IMAGINE Enlarged Platform Architecture, version 3

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Executive Summary

In the manufacturing domain, if production is to run smoothly, a DMN must have complete insight into the management and control of the production processes, raw materials necessary for production, work progress, suppliers and shipment information, etc. This is where a production analytics and monitoring solution can offer manufacturers insights for making informed decisions so that the production line does not get hampered and the overall production runs according to plan and does not suffer.

Objective of the IMAGINE architecture v3 is to extend architecture v2 in order to achieve accurate, complete manufacturing data and event, visibility in a timely fashion and production-wide consistency according to stipulated production plans, deadlines and performance criteria. A major part of the IMAGINE architecture v3 is to track material movement, consumption, asset and resource utilization, and pull data from various manufacturing sources to transform it into information suitable for analysis to gain "intelligence" to gain DMN visibility and support improved production decisions. IMAGINE architecture v3 is intended to handle real-time production data to support DMN managers and factory-based employees in making improved decisions. It intends to deliver real-time metrics, drill-down capabilities to see root causes of problems to operators, line workers, supervisors and plant managers managing operations for their scope of control, on the basis of complex manufacturing events. In a modern, dynamically changing manufacturing environment it is very important to ensure mechanisms for sensing changes (internal, external context) and provide efficient approaches for understanding their impact on the whole DMN process. This is the main role of the dynamic monitoring, a novel DMN real-time monitoring approach that will enable above mentioned decision-making agility.

This deliverable takes a long-term holistic view vis-à-vis production analytics and production monitoring on the basis of complex events and proposes a reference architecture to drive improvements or increase production. The production analytics and production monitoring reference architecture can lead to smarter manufacturing applications that maximize the transparency of the entire production process. It confers enhanced competitive advantages to manufacturing by improving decision making on the basis of production and quality aspects of most important production assets – data, resources and processes - to attain a wide-ranging view of a DMN's production and performance and identify potential issues proactively. It should be noted that due to the complexity of the reference architecture and limited resources only its core elements will be implemented in IMAGINE. This aspect will be considered by the IMAGINE Design and reflected in the IMAGINE Platform implementation and will be further discussed and detailed out in IMAGINE integrated platform, Release 3 as part of deliverable D3.2.3.

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1 Introduction and Rationale for Event-Driven Production

1.1 Introduction

Even in the most controlled production environments, unexpected events can happen that may have direct impact on the production process and the quality of the final product. Non-conformance to product targets, quality and deadlines that arise need to be tracked and recorded for analysis and remediation. Evidence of anomalies must be included in a record, along with appropriate details of when the event occurred, the production phase in which it occurred, details of the incident or observation, level of criticality and required follow-up by the operator(s) and/or supervisors, e.g., DMN manager. Moreover, in the highly changing environments, where the modern manufacturing enterprises operate in, it is very important to be able to spot in real-time and understand relevant changes that might impact the manufacturing process. This can be a very challenging task in the era of big data processing, which has become ever more important for the manufacturing domain. We have introduced dynamic monitoring as a systematic approach for sensing dynamics from different sources, their efficient real-time integration and interpretation in the proper DMN context, in order to enable making informed real-time decisions, especially in critical situations.

Typical information that needs to be displayed on dashboard for observation and/or action, includes the following details:

- Time and date the event occurred
- Batch number, product produced
- Phase of the batch where the event occurred
- Specific details of the incident or observation, including:
  - Type of anomaly
  - Target value
  - Actual value
  - Reason for the incident
  - Severity of the incident
- Links to standard operating procedures for managing anomaly,
- Required follow-up steps with signatures of responsible operators and supervisors,
- Information about relevance of events for the overall production process (only appropriate production-related events are worth being intercepted by the DMN manager).

To address such serious issues the i_platform must track production anomalies caused by such things as item substitutions, resource substitutions, resource malfunctions, as well as any ad-hoc operator observations, such as power outages. Notifications of any anomalies must be routed electronically to alert the appropriate individuals so that production status can be determined and appropriate actions can be initiated.

To achieve its extended functionality the IMAGINE architecture v3 will concentrate on the concept of production analytics and Complex Event Processing (CEP), which comprise essential parts of its monitoring functionality. Complex Event Processing techniques have been briefly mentioned in D2.3.1 – "IMAGINE Platform Technological Foundation".

This deliverable will in particular illustrate how the monitoring in architecture v2 and the IMAGINE blueprints can be extended in a non-intrusive manner to deal with production metrics and analytics on the basis of complex event technology.

1.2 Purpose and Scope of this Deliverable

In this deliverable we shall provide the third improved version of the i_platform. In particular, this deliverable will further scope, refine and where needed extend the second version of the i_platform architecture. As with second version of the architecture the third version will also be of generic nature but can be extended to cater for living lab specific requirements and needs. However, realizations of the generic platform may differ, depending on specific constraints of the different living lab.

The third version of the architecture focuses predominantly in providing greater real-time control over production activities and resolve issues that prevent work progress or result in inferior products. Key usability features include exception resolution allowing DMN managers supervisors to easily assign alternative production resources, anticipated capacity resource shortages for proactive staffing changes and a supervisor dashboard for real-time views of the activities on the enterprise level or shop floor.

To achieve its stated objectives IMAGINE architecture v3 will enhance the functionality of the architecture v2 with advanced functionality that allows dynamic monitoring of production and product quality. This functionality will be based on Complex Manufacturing Event Processing (CMEP) and will result in:

- Aggregating operational data from multiple data sources (including production schedules and blueprint supplied information), diverse business lines, partners, across the DMN.
- Efficient modelling and detection of the real-time situations of interest that the system should react on
- Measuring production process performance against strategic company initiatives.
- Gaining a high-level overview of performance across key areas such as production quality control and fulfilment.
- Monitoring operations or supplier performance by a specific metric (KPI) such as on-time delivery.
- Tracking financial goals in terms of simple key controllable expenses.

1.3 Structure of the Deliverable

This deliverable is structured as follows. Section-1 provides a broad overview and the use of events in production environments. Section-2 introduces the notion of production analytics and provides insights into production analytics in the context of product development and production processes and in DMNs. It also explains how production analytics in IMAGINE are dealt with using an event-based analytics approach. Section-3 provides an overview of the production metrics and measurements used in IMAGINE. Section-4 provides an overview of Complex Event Processing technology that will be used in conjunction with monitoring functionality in the third version of the IMAGINE architecture. Senction-5 connects event processing to the service oriented approach espoused by IMAGINE. Section-6 discusses relevant standard approaches to manufacturing analytics found in standards such ISA-95 and SCOR. Section-7 discusses how production efficiency improvements suggested by standards such as ISO18435 are related to the IMAGINE production indicators that were introduced in section-3. Section-8 introduces the characteristics of event-driven manufacturing in IMAGINE and relates them to production analytics. Section-9 describes the reference architecture developed on the basis of complex events by project participants that can be used as standard architecture for production analysis and monitoring purposes in a large number of manufacturing environments. This architecture will constitute the basis for the IMAGINE architecture v3. It also introduces a simplified view of this reference architecture which serves as the IMAGINE architecture v3. Section-10 presents the production-oriented flow introduced in previous deliverables in the context of the IMAGINE architecture v3. Finally, section-11 describes the extensions needed for the Quality Assurance Blueprints as a result of the introduction of the IMAGINE architecture v3.

2 Production Analytics

Manufacturers in a DMN need to gain insights into product development and production processes, production segment performance, and an understanding of different ways in which production costs are affected. This is shown in the figure below. Production concerns in a DMN can be summarised as follows:

- Schedule, track production activity,
- Way the production is running,
- Ways to improve production, and
- Production deadline management

In addition to production concerns we also experience quality concerns such as the following:

- How product was made, ensure compliance
- Ways to improve product and yield
- How can I quickly respond to quality issues in manufacturing execution?

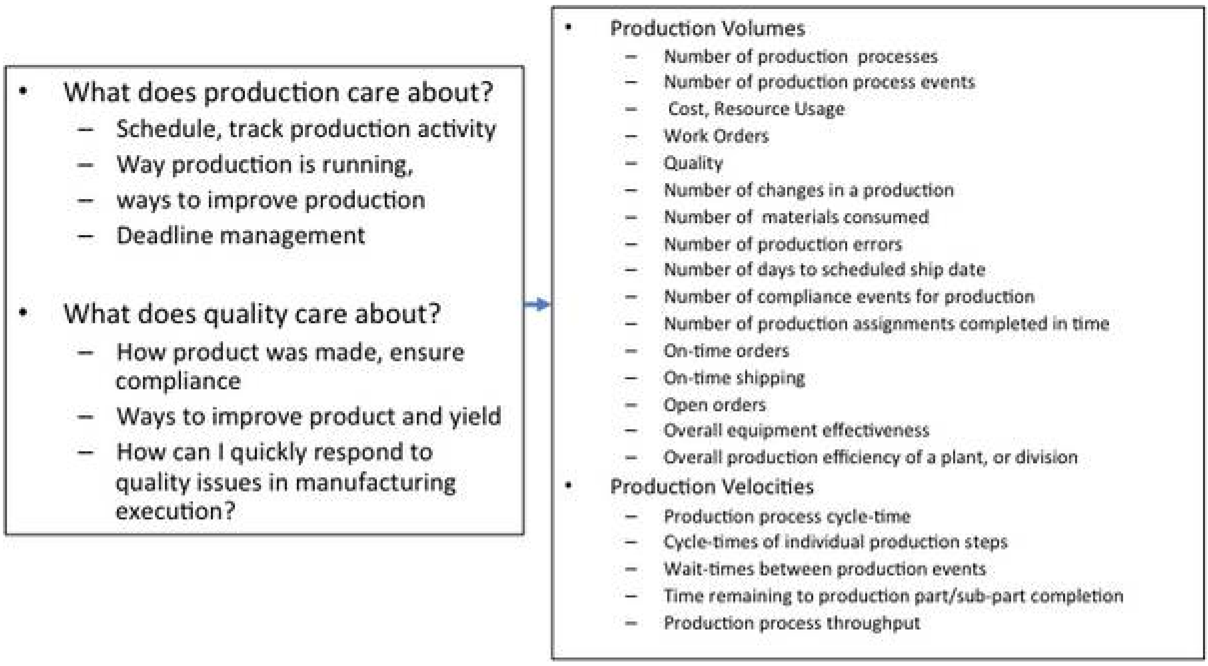

Figure 2-1 Production and quality concerns during manufacturing

Figure 2.1 illustrates how these two types of concerns are associated with production volumes and velocities. In fact Forbes predicts that large-scale data gathering and analytics are quickly becoming a new frontier of competitive differentiation in manufacturing [1].

To address concerns such as the ones stated above, smart manufacturing is achieved through identifying the overall effectiveness of the manufacturing operations - from the shop floor through to the enterprise floor. Tying machine level data to inventory and batch level production mandates will provide a holistic view of the entire manufacturing operation. Transforming the real-time, historical and business data collected during production activities through the i_platform will provide the synergy between execution and analytics - the ability for DMN managers and product/quality engineers to take decisions based on production data traces. The responsiveness that DMNs can realize through analytics from the data collected through during manufacturing will prove to be invaluable in increasing productivity and product quality. Finally, sensing and proper interpretation of the dynamics of changes in calculated analytics is an important mechanism for ensuring the validity/actuality of the information provided/presented to various decision makers. Therefore, in order to be efficient in highly changing environments, monitoring of production analytics must be dynamic.

2.1 Production Analytics

Production management analytics (or simply production analytics) tracks all aspects of the manufacturing or production. Developed for DMN management, it will provide accurate records as well as real-time information of the production process including details of defect tracking and complete product genealogy. In doing so, it will enable the communication of real-time manufacturing data from the shop or enterprise (business-level) floor to the decision makers when they need it.

Production analytics address the need for accurate real time asset *performance analysis* on the plant (shop) floor, thereby speeding up the decision-making and planning of production processes. The information made available assists in the achievement of robust manufacturing practices by clearly identifying downtime duration and reasons, generating production performance against plan reports, calculating quality performance and monitoring overall equipment effectiveness.

Production analytics also encompasses *production process analytics* to enable the improvement of overall profitability and effectiveness in production processes (operations) by providing information on several critical, interrelated areas of production. These areas include the ability to better utilize plant assets (such as people, equipment and materials) through a single or multi-site view of overall equipment efficiency. This implies such advanced functionality as:

- Enabling route validations to ensure there are no deviations from the determined process routes within the production environment,
- Performing real-time data validations on all products. Lots and products that pass pre-specified tolerance thresholds can automatically move to the next process step
- Analysing production information and get to the root cause of issues to rework products in real-time to increasing first pass yield.

The fundamental data elements of performance analytics are derivatives of production metrics represented in the form of production Key Performance Indicators (KPIs). These elements of information define the important operational factors of the machine, production line or manufacturing process. Typical metrics include production rate performance, perfect order fulfilment, overall equipment effectiveness, equipment utilization, equipment reliability, equipment throughput, equipment status, equipment availability, total rework by process, total rework by tool, defects by lot, and defects by product. These will be described in some depth in the following section.

Production analytics assists the DMN with the following important functions:

- Plant wide visibility into production execution and manufacturing quality against targets and budgets,
- Summary level KPIs with drill downs to detailed root cause analysis of inspection plans and quality test results,
- Manufacturing execution including production performance, material and resource usage and work order analysis for process manufacturing,
- Production quality and quality test results,
- Production plan comparison, and schedule adherence,
- Analysis of current state manufacturing execution against targets and historical trends,
- Tracking all major points in the process, by work order and operation,
- Tracking costs, quantities and amounts of usage,
- Tracking dates between major points in the production process,
- Monitoring and controlling shop floor execution.

The characteristics of effective production analytics can be summarised in the following:

- Aggregation, analysis, visualization, reporting of manufacturing data,
- Role-based presentation,
- Rule-based cause analysis,
- Identification of significant events and associate production KPIs,
- Enabling drill-down, data exploration, and identification of problem sources before they affect quality or cost.

In summary, performance production and process analytics can help manufacturers of multiple products make adjustments to production and offer the ability to improve cost control and product flow that can truly dictate the health and long term sustainability of a DMN.

2.2 Production Analytics in IMAGINE

Production analytics in IMAGINE will be dealt with an event-based analytics and tracking module which will extend the IMAGINE architecture v2 and will offer an integrated view of planning, design, manufacturing execution, and manufacturing quality. This module will provide a meta-level processing of the manufacturing-relevant information (already available in the previous architecture), putting it in the context of the production and quality concerns/goals presented in Fig. 2.1. Purpose of this module will be to:

- Define the goals of the dynamic monitoring of the production analytics (by providing specific patterns to be monitored)
- Monitor the near real-time information relevant for the DMN process, as

  - Track and analyse current state manufacturing execution against KPI targets and historical trends,
  - Track all major points in the process by work order and process operation,
  - Track costs, quantities and amounts of usage,
  - Track dates between major events/ points in the production process.
- Create real-time awareness about situations of interest (real-time detection of monitored patterns)
- Enable continuous refinement of the monitoring goals and patterns based on the dynamics of the internal and external context

The IMAGINE production analytics module in IMAGINE architecture v3 will be able to assist individuals with the issues related to the production and quality goals (as described in section 2.1), leading to the resolution of many relevant questions for a DMN manager, like:

- Has Manufacturing started on time?
- Is the DMN producing according to plan?
- Has the required production process event occurred on time?
- Will the order adhere to schedule and ship on time?
- Does this order meet our On-Time Delivery Goal and quality KPIs?
- If not, why not?
- What % of completions were scrapped and reworked?
- What are the bottlenecks in the current production process?
- How much revenue was lost due to rework and scrap?

Note that these questions are indicative and the concrete list of questions depends on the use case analysis performed in deliverable D2.1.2 "Extended IMAGINE platform use cases". Dynamic monitoring methodology will provide guidelines for defining questions of interests that will lead to the situations of interests that should be detected in real-time. The provided list of KPIs (defined a priory) will be used as the starting point in deriving this very valuable corporate knowledge, as detailed in the next section.

The production analytics module will be able to create different types of reports including:

Production Overview Analysis: With this report a DMN manager can gain an overview of production totals by production partner, production to plan ratio, production service level by work center, and material group.

Production/Capacity Utilization Analysis: This report provides an overview of capacity utilization for production. The DMN manager can also check the overdue backlogs status using this report. The report allows root cause analysis down to the level of orders.

Production Lead Time Analysis: This report provides an overview of the breakdown of the lead time for production.

3 Overview of Production Metrics & Measurements

Production solutions such as those envisaged by IMAGINE must give DMN and production/plant managers better visibility into customer demand and inventory supply situations so they can improve any deficiencies and optimize production efforts. With globally distributed operations, DMN production solutions must be able to provide visibility into production statistics, work-in-progress details, and logistics information so DMN and production mangers can better manage the end-to-end manufacturing process. Improving manufacturing processes can result in reducing production cycles, decrease the cost of manufactured products, and improve information accuracy and decision making.

3.1 Production Measurements

In so far as performance measurement is concerned, IMAGINE follows the philosophy of the IT Performance Management Group (ITPMG) [2], which states that the most basic benefits derived from measurement, are the opportunities to increase one's knowledge and at the same time to reduce uncertainty. This results in increasing the accuracy of decision-making thus, reducing risk. This is done by making observations by means of measurement and processing these observations into information. The four forms of observations mentioned by ITMG, which are relevant to IMAGINE performance measurement, are the following [2]:

1. Characterisation: Its objective is to describe, to gain understanding and to establish baselines for future comparison.
2. Evaluation: This is to determine the status with respect to plans. Measurements are the sensors that provide the signals when processes are not meeting targets, so that they can be brought back under control. Here, one can also assess achievement of quality goals and to the impact of improvement.
3. Prediction and preparation: To predict so that an organization can plan and prepare. Measuring for prediction involves gaining understanding of relationships and building models of these relationships, so that the values observed for some attributes, can be used to predict others. This is done because one wants to establish achievable goals so that appropriate resources can be applied.
4. Improvement: To identify roadblocks, root causes, inefficiencies and other opportunities for improvement. Measurements help plan and track improvement efforts. Measurements of current performance provide baselines to compare against, so that we can judge whether improvement actions are working as intended and what the side-effects might be.

KPIs assist the organization to define and measure progress toward organizational goals and objectives. Once the organization has analysed its mission and defined its goals, it needs to measure progress towards those goals. KPIs provide a measurement tool.

KPIs assist an organization to measure that it is 'on track' – most often, that it is working towards and attaining a beneficial outcome or improvement. In manufacturing KPIs are detailed from a top-down perspective, from the plant manager to the production supervisor, and then aligned with plant operations from the bottom up, starting with the production supervisor up to the plant manager. This alignment of KPIs is used to produce a balanced and consistent window through which the manufacturing network can be viewed.

A recent Vertical View Survey by IDC Manufacturing Insights indicates that the top priority for manufacturers is to improve productivity [3]. Managers and supervisors are central to this undertaking as they must be able to guide rapid action for their scope of control based on the current situation in each sub-segment the organization serves. Clearly improved knowledge on production performance is highly correlated to greater financial performance.

In addition to the formally defined Production Performance data model defined in the ISA-95 standard, there is additional information about production that provides summaries of past performance, indications of future performance, or indicators of potential future problems (leading indicators). Collectively, this information is defined as "Production Indicators" (or shortly production KPIs).

Production indicators can be as simple as values of process tags used as inputs to complex process models. There is a core set of values related to production output, but there can be a significant variation in the core set based on the vertical industry, e.g., automotive, aerospace, semiconductors, etc.

Typical examples where production KPI metrics can be analysed and combined to yield more robust decision-making capabilities include:

- Product design and innovation decisions based on issues in production and in suppliers' facilities such as suitability to run on current equipment,
- Traceability of materials and containment of problems that could cause a customer problem or recall across the global enterprise and supply chain,
- Customer service promises order due dates and/or quantities based on actual capacity and progress of in-process work and orders.

It may be useful to group KPIs into categories based on organization's vision, strategy and objectives. Grouping production KPIs into categories may also assist in testing KPI applicability, relevance and potential overlaps or conflicts.

For IMAGINE architecture v3 the four broad categories listed below may serve as a starting point:

- Perfect Order Fulfilment
- Production efficiency,
- Production quality, and

- Equipment Effectiveness.

These categories are partially based on the findings proposed in ISA-95-Based Operations and KPI Metrics Assessment and Analysis [4] and in [5] and are summarized briefly below.

3.1.1 Perfect Order Fulfilment

Figure 2.1 shows the metrics associated with a perfect order fulfilment. These include the following characteristics:

- An order is considered perfect if the products ordered are the products provided and the quantities ordered match the quantities provided (measured in % of order completed in full).
- A delivery is considered perfect if the location, specified customer entity and delivery time ordered is met upon receipt (Delivery Performance to Customer Commit Date).
- The product condition is considered perfect if the product is delivered / faultlessly installed (as applicable) on specification, with the correct configuration, with no damage, customer ready, and is accepted by the customer (Perfect Condition).

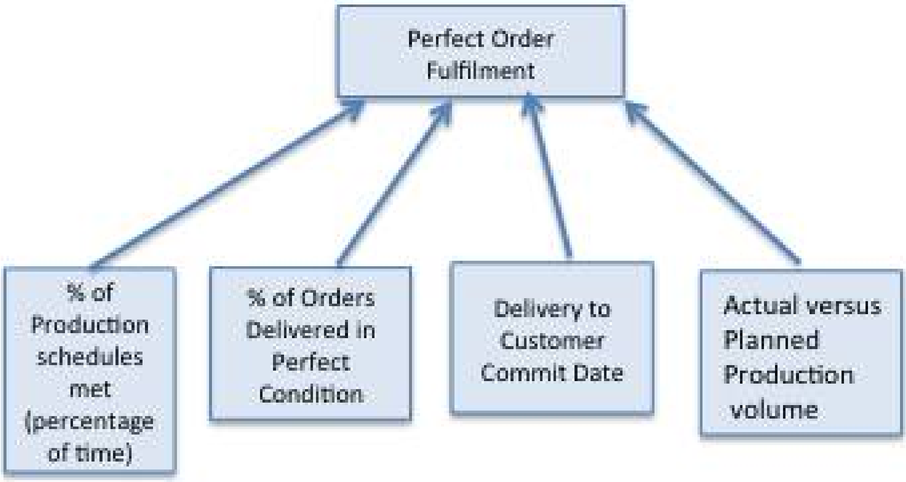

Figure 3-1 Characteristics of perfect order fulfilment

3.1.2 Production Efficiency

Production efficiency can be divided into several sections according to plant structure and other significant factors. Figure 3.1 summarizes potential indicators for production efficiency assessment.

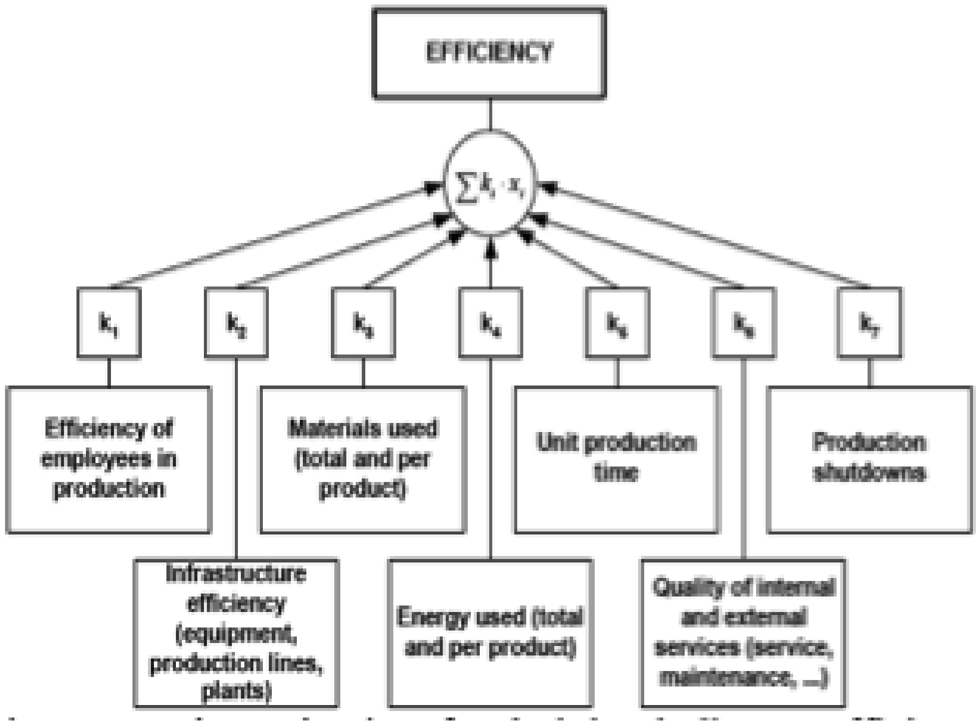

Figure 3-2 Schematic overview of production efficiency KPIs

Other KPIs that may be connected with production efficiency (not shown in Figure 3.2) may include:

– Product Count: An essential factory floor metric relates to the amount of product produced. The count (good or bad) typically refers to either the amount of product produced since the last machine changeover or the production sum for the entire shift or week.
– Reject Ratio: Production processes occasionally produce scrap, which is measured in terms of reject ratio. Minimizing scrap helps organizations meet profitability goals so it is important to track whether or not the amount being produced is within tolerable limits.
– Production Rate: Machines and processes produce goods at variable rates. When speeds differ, slow rates typically result in dropped profits while faster speeds affect quality control. This is why it is important for operating speeds to remain consistent.
– Product Target: Many organizations display target values for output, rate and quality. This KPI helps motivate employees to meet specific performance targets.

3.1.3 Production Quality

Quality plays a significant role in the production environment. It is related to materials used, final products, production processes and services. Typical production quality characteristics can be found in Figure 3.3.

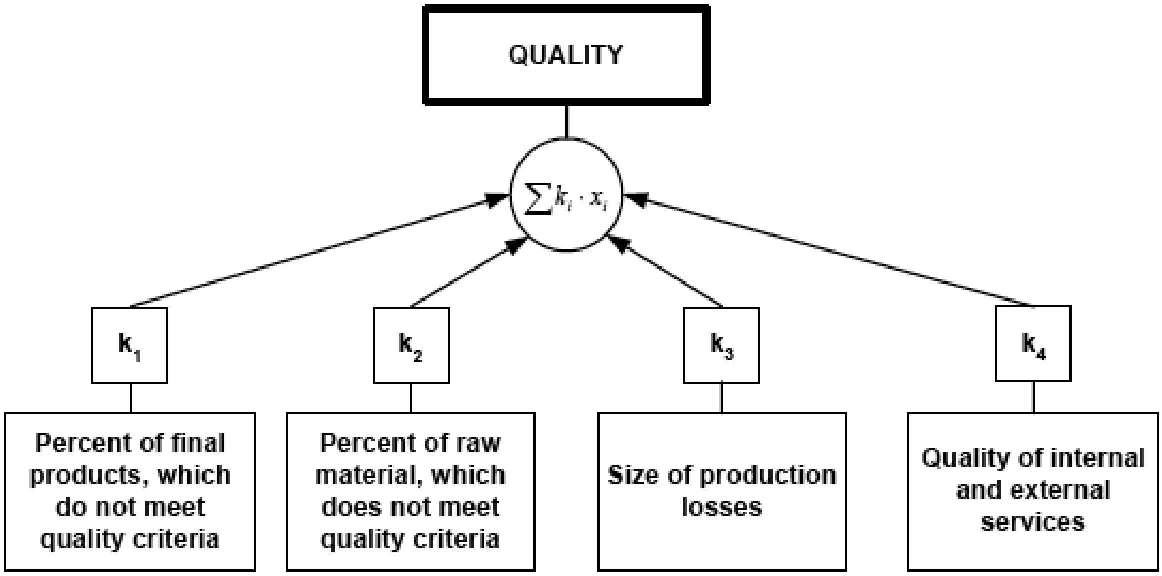

Figure 3-3 Schematic overview of production quality KPIs

3.1.4 Production Equipment Effectiveness

Production Equipment Effectiveness is a metric that multiplies availability by performance and quality to determine resource utilization. Production managers require production equipment values to increase because this indicates more efficient utilization of available personnel and machinery. The attributes of production equipment effectiveness are shown in Figure 3.4.

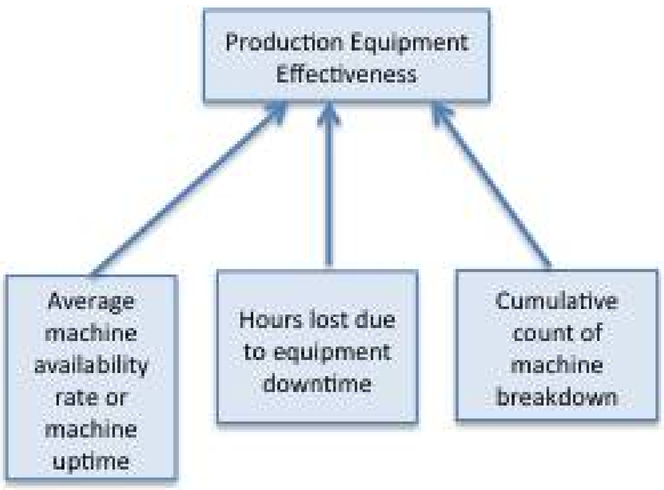

Figure 3-4 Schematic overview of production equipment effectiveness

Equipment downtime is considered one of the most important KPI metrics to track irrespectively whether the result of a breakdown or simply a machine changeover. When machines are not operating, money isn't being made so reducing downtime is an easy way to increase profitability.

Organizations that track downtime typically require operators to enter a "reason code" via keypad, pushbutton or bar code scanner so that the most common reasons can be reviewed at a later time.

4 Complex Event Processing Overview

4.1 What is Complex Event Processing and what does it do?

Complex Event Processing (CEP) is a technology that is able to identify meaningful events out of event streams and creating complex events using correlation, abstraction and causality between events. An event is any happening of interest and could contain critical data, for example a malfunctioning machine, a supplier failure, transport delays, etc. A combination of such atomic (also referred to as primitive) events is called a complex, or composite event. Complex events are specified using event patterns, which are primitive events combined with event composition operators. An example of an event pattern is A; (B | C), signifying that an event A is followed by either event B or C. Here composition operators are the sequence (;) and union (|) operators.

Complex event processing (CEP) is a software technology for the dynamic processing of high volume events, which can be considered a perfect match for detecting critical situations. With CEP, it is possible to express causal, temporal, spatial and other relations between events. These relationships specify patterns in which the event stream is searched in real-time.

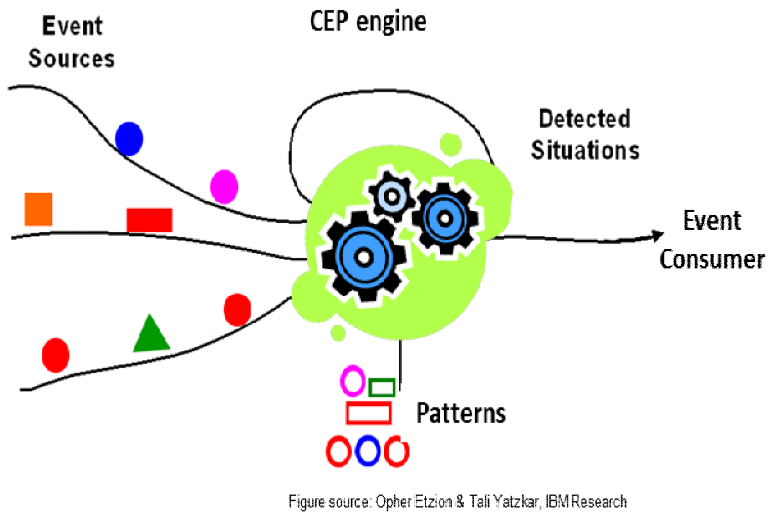

Figure 4-1 Complex event processing: basic components

As shown in the figure above, a CEP system normally consists of four parts: event sources, event consumer, CEP engine and patterns. An event is a special kind of a message and event sources generate these messages and send events to CEP system, a typical event source is a sensor or an application. Patterns (complex event patterns) describe the situations of interest presented in the form of combinations of some events with causal, temporal, spatial and other relations. CEP engine processes the events from event sources to detect the situation according to the input patterns and generates the detected situations as complex event. Esper and ETALIS are CEP engines, which has been widely used. Event Consumer receives the complex events from CEP engine to deal with detected situations. A typical event Consumer is an application (e.g. a dashboard used for visualizing events).

The value proposition of Complex Event Processing is that it is a new breed of software for enterprise event and rules management that – especially when combined with Business Activity Monitoring as envisaged by IMAGINE architecture v3 – provides analytical on-line methods that can instantaneously be applied to running production and manufacturing processes [6]. Please also refer to deliverable D2.3.1 "IMAGINE Technology". This approach offers the following advanced functionality:

- Delivers timely, contextual and highly relevant performance information via a highly customizable framework
- Detects patterns of significant business events from diverse data sources, then notifies appropriate people or autonomously launches an application.
- Monitors low level events to find higher level meaning
- Delivers much greater operational performance and "business insight"
- Recognizes operational process performance and business situations that need immediate action – identify trends, detect problems and opportunities
- Enables real time, higher level, useful business goal understanding and predictability and decision support.
- Model to Code approach to building decision platforms in SOA / EDA (Event Driven Applications)

4.2 Complex Event Processing in IMAGINE

The main role of CEP is to enable a more reactive DMN management by providing a meta-layer for real-time processing of relevant information. Indeed, we treat events as meta-level information for the production process (e.g. production control, product tracking, etc). Consequently, event processing is on another processing level (meta-level) and can be used for a better understanding of different phenomena (anomalies) in the production. From the point of view of the system reactivity, CEP provides the framework for realizing well-known OODA (Observe – Orient – Decide – Act) loop[1]. Figure 4-2 presents a slightly modified cycle, applied for the dynamic monitoring. The main difference is in paying more attention on the process of defining situations of interest (to be monitored), since our methodology is more goal-driven than a general OODA approach. Selected three phases have the following roles (see Figure 4.2):

- Prevention is responsible for the definition of the situations (complex event patterns) to be detected, that should be aligned with the production and quality goals,
- Detection is related to the awareness creation that something relevant has happened and
- Response is related to the reaction of an emerged situation in order to satisfy goals defined in the prevention phase.

[1] http://en.wikipedia.org/wiki/OODA_loop

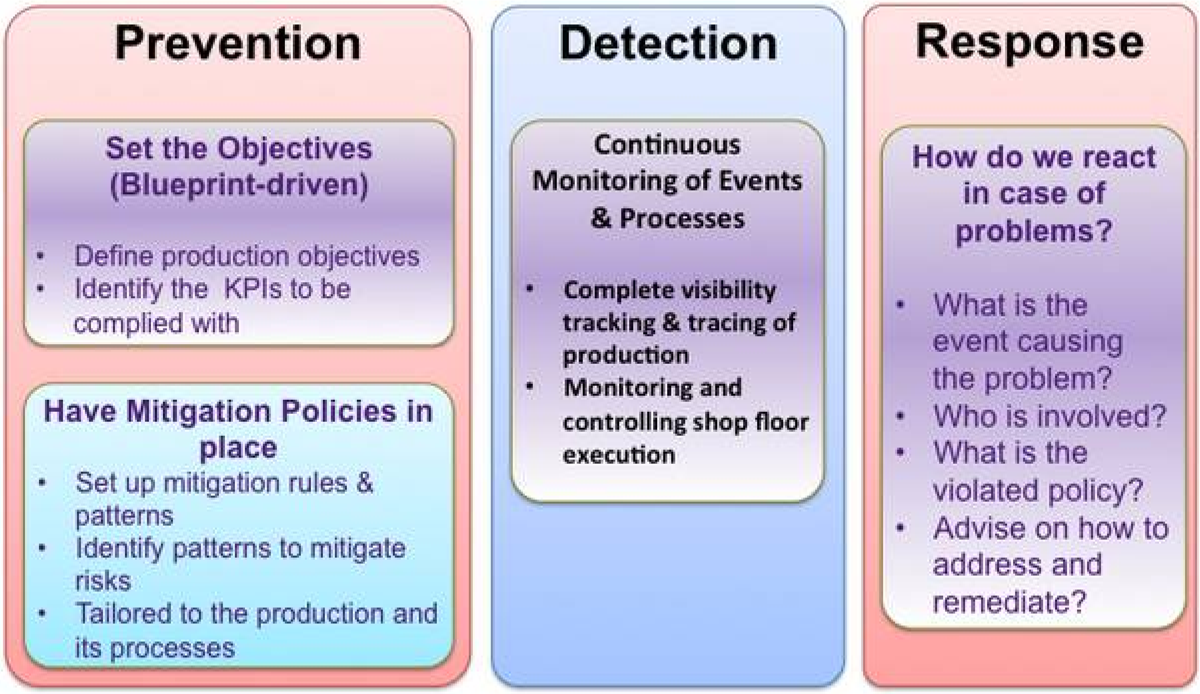

Figure 4-2 Steps in complex event processing in IMAGINE

4.3 Event Types definition

An event in a CEP system typically carries event attributes and one or more timestamps. The timestamps can refer to its occurrence time, its arrival time to the system, or can specify its duration. The event attributes specify the properties of an event (i.e. its carried payload), and must adhere to an event schema. The schema usually specifies the types and names of the attributes, as well as their format. Usually an XML format is employed in which an event carries both its schema and its properties, others rely on attribute ordering.

An event type is a class of event objects. Examples of an event type include the type of all price quotations, the type of all sensor readings for any kind of robot sensor, the shipment of materials or products, etc. An event attribute is a component of the structure of an event. An attribute can have a simple or complex data type.

As a general characteristic of an event we may note that:

- All events must be instances of an event type.
- An event has the structure defined by its type.
- The structure is represented as a collection of event attributes.
- Event types should be defined within the type definition system of a modern strongly typed computer language such as for instance, XML Schema or Java.

Events will usually specify certain standardized data attributes, such as:

- a unique event identifier by means of which the event can be referenced,
- the type of the event,
- its creation time stamps,
- its source of creation,
- Its sink (consumer).

4.4 Complex Event Patterns

One of the main roles of event processing is to enable the formalization of the organisational knowledge, esp. one which is relevant for the real-time reaction. Indeed, an important part of event processing is the definition of the situations the system should react on, which can be considered as a knowledge engineering/management task. In that context, complex event patterns can be treated as knowledge artefacts that should be generated/collected and maintained.

More information about the model of patterns and its formalization can be found in D8.1.

5 Event Driven SOA

5.1 Introduction

A Service Oriented Architecture (SOA), which was introduced in short in deliverable D2.3.1, requires an additional fundamental technology beyond the services aspect to realize its full potential: event-driven computing. Ultimately, the primary objective of most SOA implementations is to automate as much processing as necessary and to provide critical and actionable information to human users when they are required to interact with a business process. This requires the ESB infrastructure itself to recognize meaningful events and respond to them appropriately. The response could signalled be either by automatically initiating new services and business processes or by notifying users of business events of interest, putting the events into topical context and, often, suggesting the best courses of action. In the enterprise context business events, such as a customer order, the arrival of a shipment at a loading dock, or the payment of a bill, and so forth, affect the normal course of a business process and can occur in any order at any point in time. Consequently, applications that use orchestrated processes that exchange messages need to communicate with each other using a broad capability known as an event-driven SOA.

An event-driven SOA is an architectural approach to distributed computing where events trigger asynchronous messages that are then sent between independent software components that need not have any information about each other by abstracting away from the details of underlying service connectivity and protocols [7]. An event-driven SOA provides a more lightweight, straightforward set of technologies to build and maintain the service abstraction for client applications.

In an ESB-enabled event-driven SOA, applications and services are treated as abstract service endpoints, which can readily respond to asynchronous events. To achieve a more loosely coupled lightweight arrangement, an event-driven SOA requires that two participants in an event (server and client) be decoupled. With fully decoupled exchanges the two participants in an event need not have any knowledge about each other before engaging in a business interaction. The only relationship is indirect, through the ESB, to which clients and servers are subscribed as subscribers and publishers of events.

Despite the notion of decoupling in event-driven SOA, recipients of events require metadata about those events. In such situations recipients of events still have some information about those events. For instance, the publishers of the events often organize them on the basis of some (topical) taxonomy or, alternatively, provide details about the event, including its size, format, etc., which is a form of metadata. Such metadata describes published events that consumers can subscribe to, the interfaces that service clients and providers exhibit as well as the messages they exchange, and even the agreed format and context of this metadata, without falling into the formal service contracts themselves.

5.2 Example: An event-based distributed procurement process

To effectively orchestrate the behaviour of services in a distributed process, the ESB infrastructure includes a distributed processing framework and XML-based Web services. To exemplify these features, we use a simplified distributed procurement business process, which we will configure and deploy using an ESB.

In the distributed procurement business process an automated inventory system initiates a replenishment signal and thereby triggers an automated procurement process flow. During this procurement process flow a series of logical steps need to be performed.

- First, the sourcing service queries the enterprise's supplier reference database to determine the list of possible suppliers, which could be prioritized on the basis of existing contracts and supplier metrics.
- A supplier is then chosen based on some criterion and the purchase order is automatically generated in an ERP purchasing module and is sent to the vendor of choice.
- Finally, this vendor uses an invoicing service to bill the customer.
- In this example we assume that the inventory is out of stock and the replenishment message is routed to a supplier order service.

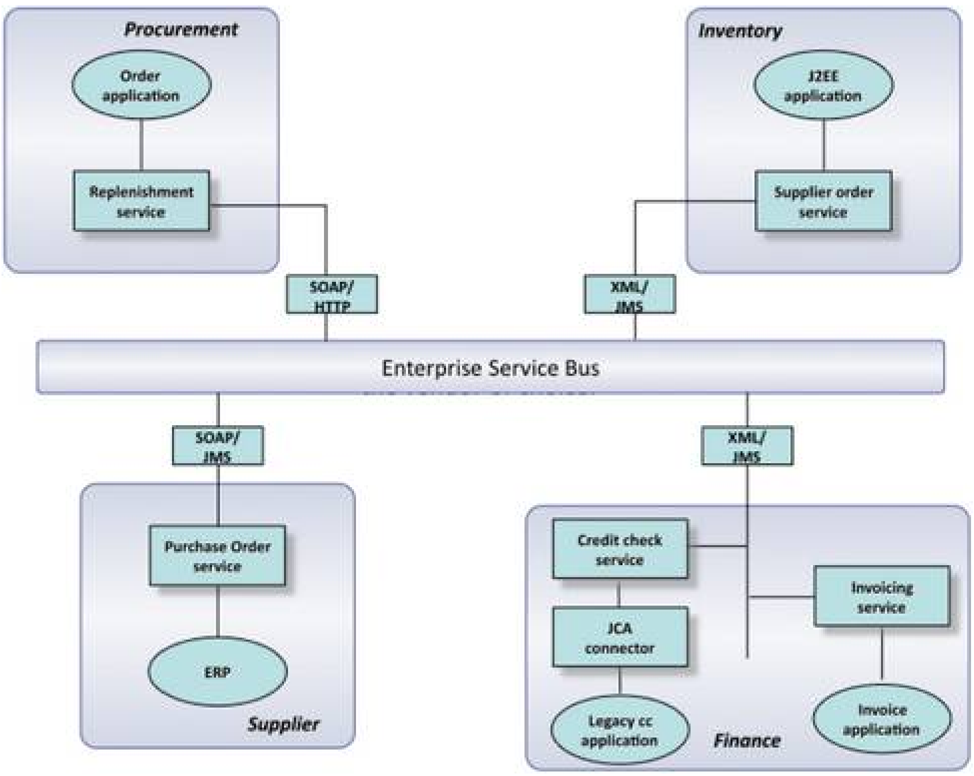

Figure 5-1 Example of an ESB connecting remote interacting services

The services that are part of the simplified distributed procurement business process can be seen in use in Figure 5.1. Although this figure shows only a single supplier order service as part of the inventory, in reality a plethora of supplier services may exist. The supplier order service, which executes a remote Web service at a chosen supplier to fulfil the order, is assumed to generate its output in an XML message format that is not understood by the purchase order service.

To avoid heterogeneity problems, the message from the supplier order service leverages the ESB's transformation service to convert the XML into a format that is acceptable by the purchase order service. This figure also shows that JCA is used within the ESB to allow legacy applications, such as a credit check service, to be placed onto the ESB through JCA resource adapters.

Once services that are part of the distributed procurement business process depicted in Figure 5.1 have been chained together, it is necessary to provide a way to manage and reconfigure them to react to changes in business processes.

The ESB is a federated environment that can be managed from any point. Ideally, this could be achieved through a sophisticated graphical business process management tool that can be used to configure, deploy, and manage services and endpoints. This allows the free movement and reconfiguration of services without requiring rewriting or modifying the services themselves.

6 ISA-95 & SCOR Manufacturing Analytics

Production execution management in ISA-95 is defined as the collection of activities that direct the performance of work, as specified by the contents of the production dispatch list elements [8]. The production execution management activity includes selecting, starting and moving those units of work (for example, lots, sublots, or batches) through the appropriate sequence of operations to physically produce the product. The actual work (manual or automatic) is part of the ISA-95 Level 2 (automated control of production, viz. shopfloor) functions.

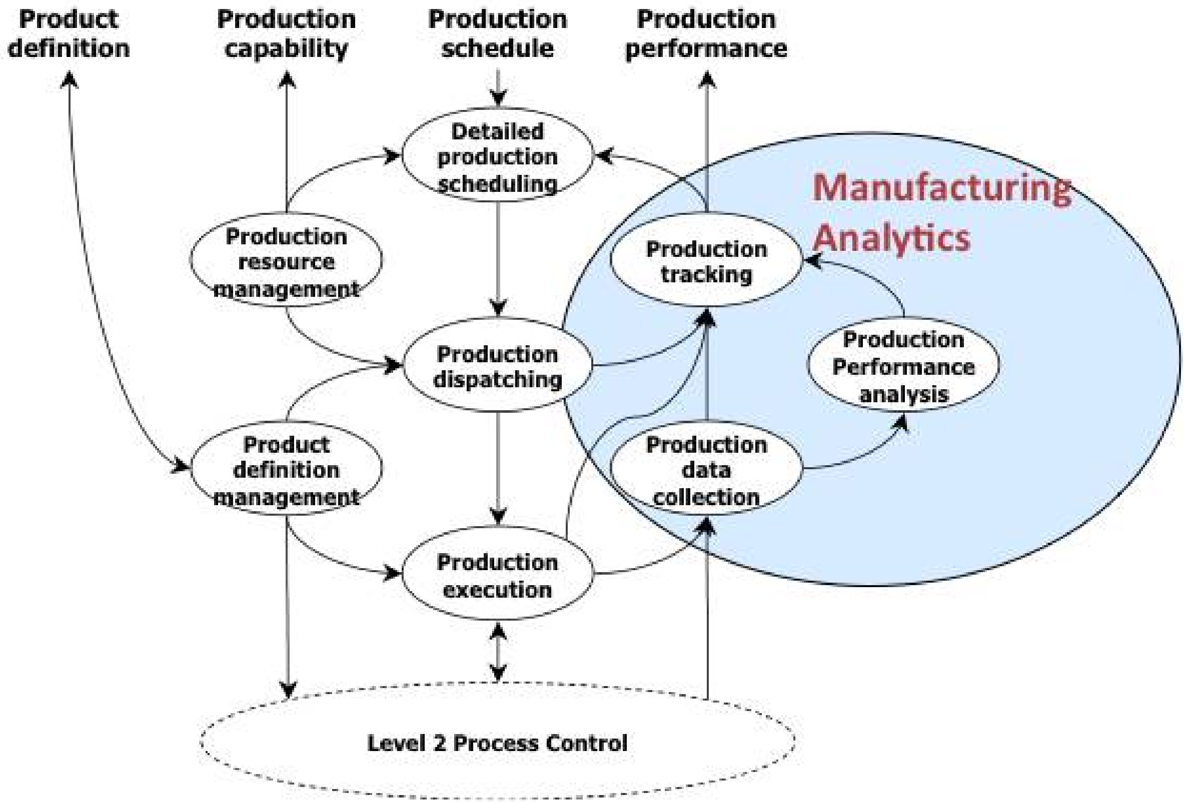

Figure 6-1 ISA-95 Manufacturing analytics model activities

6.1 ISA-95 Manufacturing Analytics

ISA-95 manufacturing analytics encompass three modules: production data collection, production tracking, and production performance analysis. These are briefly described below.

6.1.1 Production Data Collection

Manufacturing control systems generally deal with process information such as quantities (weight, units, etc.) and associated properties (rates, temperatures, etc.) and with equipment information such as controller, sensor and actuator statuses. These data may include sensor readings, equipment states, event data, operator-entered data, transaction data, operator actions, messages, calculation results from models and other data of importance in the making of a product. The data collection is inherently time- or event-based, with time or event data added to give context to the collected information. Production data collection in ISA-95 is defined as the collection of activities that gather, compile and manage production data for specific work processes or specific production requests. The focus of data collection is placed on Level-2 and deals with resource data, operations data, equipment status, equipment configuration, alarms, operator actions, and operator comments.

Production data collection in ISA-95 concerns itself with:

1. collecting, retrieving and archiving information related to the execution of production requests, equipment usage, including information entered by production personnel. Examples include: physical process data, equipment status data, lot and sublot location and amount data collection, operations logs (plant entries and comments);
2. providing interfaces to the basic process or manufacturing line control system, laboratory information management systems and production management systems for automatic collection of information;
3. providing reports on production data;
4. maintaining information for local process and production analysis and for reporting to higher-level logistics systems;
5. maintaining information for product tracking to enable tracking and tracing capability such as tracing products to specific material lots, equipment and/or operators;
6. providing compliance monitoring and alarm management functionality (event logging and sequence of events); and
7. providing collected product quality information for comparison against specifications.

6.1.2 Production Tracking

Production tracking shall be defined as the collection of activities that prepare the production response for Level 4 (Business Planning and Logistics). This includes summarizing and reporting information about personnel and equipment actually used to produce product, material consumed, material produced and other relevant production data such as costs and performance analysis results. Production tracking also provides information to detailed production scheduling and Level 4 scheduling activities so schedules can be updated on the basis of current conditions.

Production tracking tasks in ISA-95 may include:

1. following the movement of material through a plant by maintaining a description of what was in each vessel at specific times and tracing the path of all materials within the production domain;
2. recording the start and end of movements and collecting updates to lot and sublot quantities and locations as they occur;
3. receiving information from production data collection and production analysis; for example, information on materials consumed in the production of a lot (an important part of the product tracking and tracing) and information on plant environmental conditions during the production of the lot;

4. translating process events, including production and movement events, into product information;
5. providing information for tracking (recording) and tracing (analysis);
6. generating production responses and production performance information. The information may be provided on demand or on a defined schedule and may be provided to people, to applications, or to other activities;
7. generating records related to the production process. This may include records required for regulatory or quality management purposes.

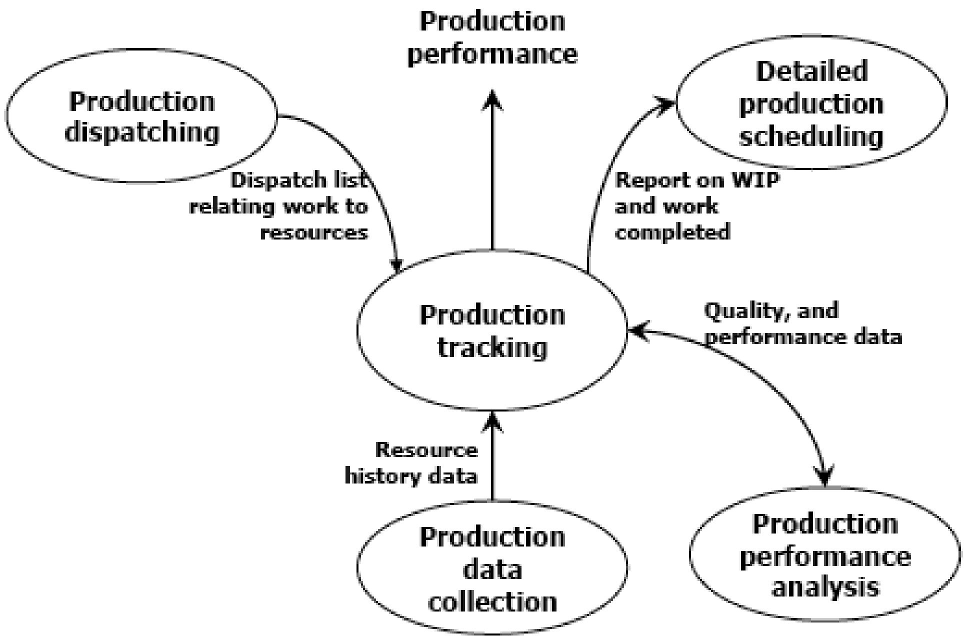

Figure 6-2 Production tracking activity model interfaces

Production tracking may involve compiling production data into business information on actual production including in-work inventory, raw material usage, and energy usage. Production tracking may require combining resource history data from multiple batches or runs into a single production performance report. Alternatively, it may require splitting information about a single batch or run into multiple production performance reports. These are illustrated in Figure 6.2.

Examples include the production history from multiple production lines used in completion of a single order may be combined to produce a single production response for the order. It is noteworthy that information from a single production run may be split into multiple production performance reports, one report for each shift used in the production.

In a DMN usually a portion of a product run may be sent to an outside entity to perform a portion of the life cycle of completing the product. In this case, the product would share history until it leaves the internal manufacturing processes and upon return to the normal internal manufacturing processes, the same product would have a slightly different history than its peer product.

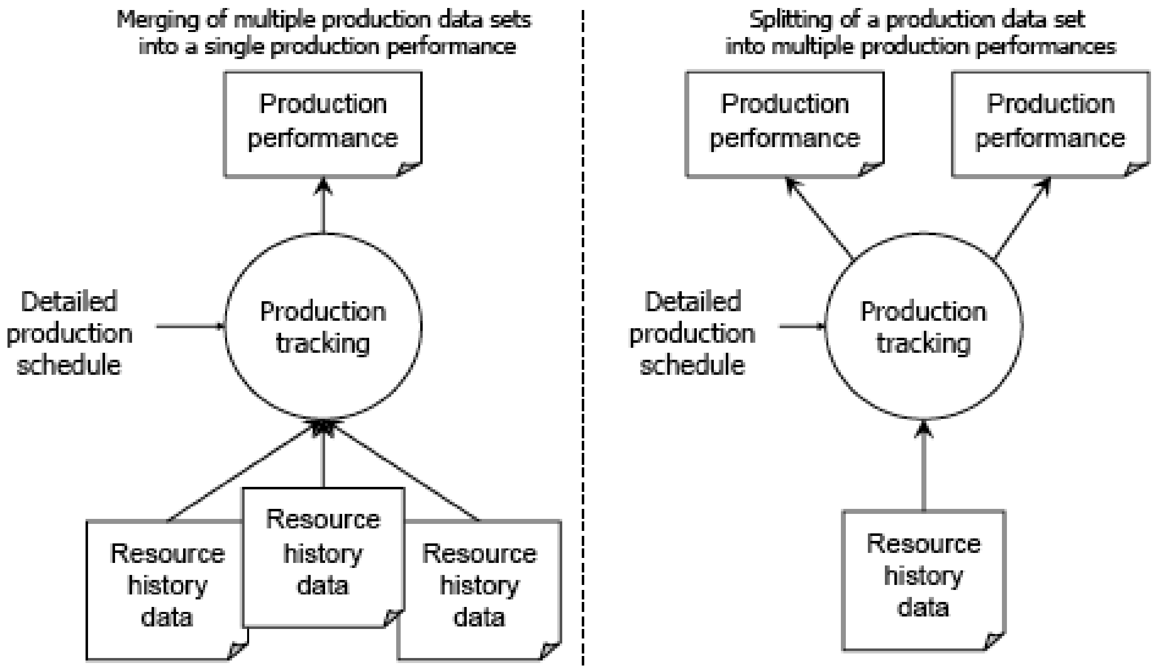

Figure 6-3 Merging and splitting production tracking information

6.1.3 Production Performance Analysis

Production performance analysis in ISA-95 is defined as the collection of activities that analyse and report performance information to business systems. This would include analysis of information of production unit cycle times, resource utilization, equipment utilization, equipment performance, procedure efficiencies and production variability. This information is used to create KPIs and optimize production and the use of resources. Such information may be provided on a scheduled basis, it may be provided at the end of production runs or batches, or it may be provided on demand.

The process of production performance analysis is on-going. Once an optimization has occurred and a constraint has been exploited, other system constraints may arise. In a changing environment, production performance analysis activities regularly re-examine throughput and policies under current and expected conditions in order to maximize system throughput.

Production performance analysis tasks in ISA-95 may include:

1. producing reports of performance and cost;
2. evaluating constraints to capacity and quality,
3. performing performance tests where necessary to determine capacity;
4. comparing different production lines and creating average or target runs;
5. comparing and contrasting one run against another;
6. comparing production runs to identify the best ever produced run (“golden” run) where best run may be defined as the highest quality, or lowest cost, or any other criteria.
7. determining why the “golden” runs are exceptional;
8. comparing runs against defined “golden” runs;
9. providing changes to process and procedures based on the results of the analysis for continuing process improvements;

10. predicting the results of a production run, on the basis of current and past performance. This may include the generation of production indicators;
11. correlating the product segments with process conditions at the time of production.

A typical example here may be to answer the question of the form "what activity happened, how it happened (what set points were used, which procedure, etc.), where it happened, when it happened and who performed it?". This will include the record of work order elements, product segments and process segments and their times, quantities and conditions of production could be searched and manipulated.

Product performance analysis encompasses the steps of: product traceability analysis, product analysis, process analysis. These are explained briefly below.

Resource traceability analysis shall be defined as the collection of activities that trace the history of all resources (material, equipment and personnel) in terms of the process actions and events that dealt with the resources in production.

Resource traceability analysis may include analysis on:

- materials produced, consumed, stored and moved;
- equipment used in production, testing and storage;
- personnel involved in the production and storage of material and operation of equipment.

Testing for product quality is one of the most important manufacturing operations activities in ISA-95. The testing may be in-line, at-line, or off-line. Product analysis also includes the off-line analysis typically performed in laboratories and the management of quality test procedures. Product analysis (quality assurance) activities include display of in-process information, such as statistical process control (SPC) or statistical quality control (SQC) data. Quality management handles the quality test procedures and often maintains quality test results.

Process analysis provides feedback about specific manufacturing processes across multiple production runs or batches. This information is used to optimize or modify specific production processes. The activity includes analysis of bad production runs to determine the root cause and analysis of exceptional quality production runs to determine optimal running conditions. Process analysis often includes SPC/SQC analysis and process modelling and uses information collected from the multiple activities that measure operating parameters.

7 Diagnostics and Capability Assessment in ISO 18435

Production efficiency improvements demand more visibility into and better management of manufacturing assets. Production improvements can be introduced if a production can have current information about the status and capability of the deployed resources.

As shown in Figure 7.1, the production capacity for the manufacturing resources, excluding consumed materials, is depicted over time. Production capacity is directly related to the family of production indicators that were introduced in section-3. Production capacity variations in height of the current available capacity indicate changes due to projected asset availability. The current unattainable capacity is due to down time for maintenance, mismatch in production capability and product mix, and other resource related issues.

Ideally, the closer one can operate with the current committed capacity to the current available capacity, the more efficient the resources are utilized. Better management of the factors impacting unattainable capacity can improve confidence in the available capacity in the future.

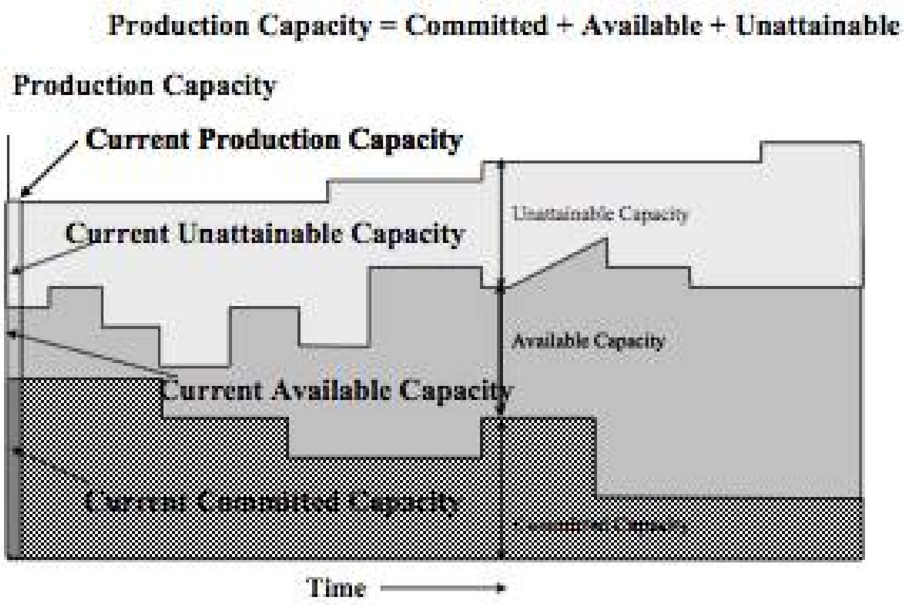

Figure 7-1 Production capacity (source [9])

Different operational and maintenance strategies can be used to ensure that the resources deployed are available when needed. The Condition Based Maintenance (CBM) approach, which introduces the ability to diagnose and perform maintenance based upon actual asset conditions has enabled more responsive maintenance strategies and is used to ensure the manufacturing assets were available when needed. Goal of the ISO 18435 standards activity is integrating CBM related information along with other operating environment information to optimize operating decisions for effective and efficient manufacturing [10].

The main focus of ISO 18435 is to describe the integration requirements that manufacturing assets and resources need to meet in order to support the operation and maintenance phase within a manufacturing system's lifecycle. The intended users of ISO 18435 are developers of industrial automation applications, especially those that design, implement, deploy, commission, and operate the required systems which integrate diagnostics, capability assessment, control, production, and maintenance applications. As several of the production analysis and monitoring functions have distinct similarities with the philosophy of ISO 18435, we shall briefly summarise the most important aspects of this standard below.

7.1 ISO 18435: Diagnostic, Capability Assessment, and Maintenance Applications Integration

ISO 18435 provides diagnostics and maintenance related activities which offer effective mechanisms for adapting maintenance strategies to various changes in manufacturing operations, such as changes in production requirements, changes in operational conditions and environment, and changes to continuously improve manufacturing assets during their lifecycle. For example, activities deal with the operational phase of maintenance task execution, which consists of maintenance task planning, involving asset inspection, monitoring and diagnostics, followed by treatment or repair if needed, and ends in the evaluation of maintenance results. These activities are mainly concerned with controlling routine maintenance tasks.

ISO 18435 also provides a combination of activities that focus on maintenance strategy planning that involves the selection of an approach for performing maintenance appropriate to each asset with options such as breakdown maintenance (BM), time-based maintenance (TBM) and condition-based maintenance (CBM) [10]. The maintenance strategies can be improved based on diagnostic capability assessment and maintenance histories.

Although condition-based maintenance (CBM) can be regarded as an advanced strategy, it is not always the most cost-effective method. When failures of machines or components are not critical, the breakdown maintenance (BM) approach is preferable. When the remaining useful life of machines or components can be estimated, time-based maintenance (TBM) is preferred [10].

The following are examples of integration issues concerning aspects of quality, cost and delivery concerning ISO 18435 maintenance task execution:

- quality aspect: conditions of manufacturing assets, kept by the maintenance tasks, used in product quality assurance;
- cost aspect: trade-off between maintenance cost and production loss due to malfunction, unsafe condition and inefficiency of assets;
- delivery (time) aspect – coordinating maintenance schedule with production schedule.

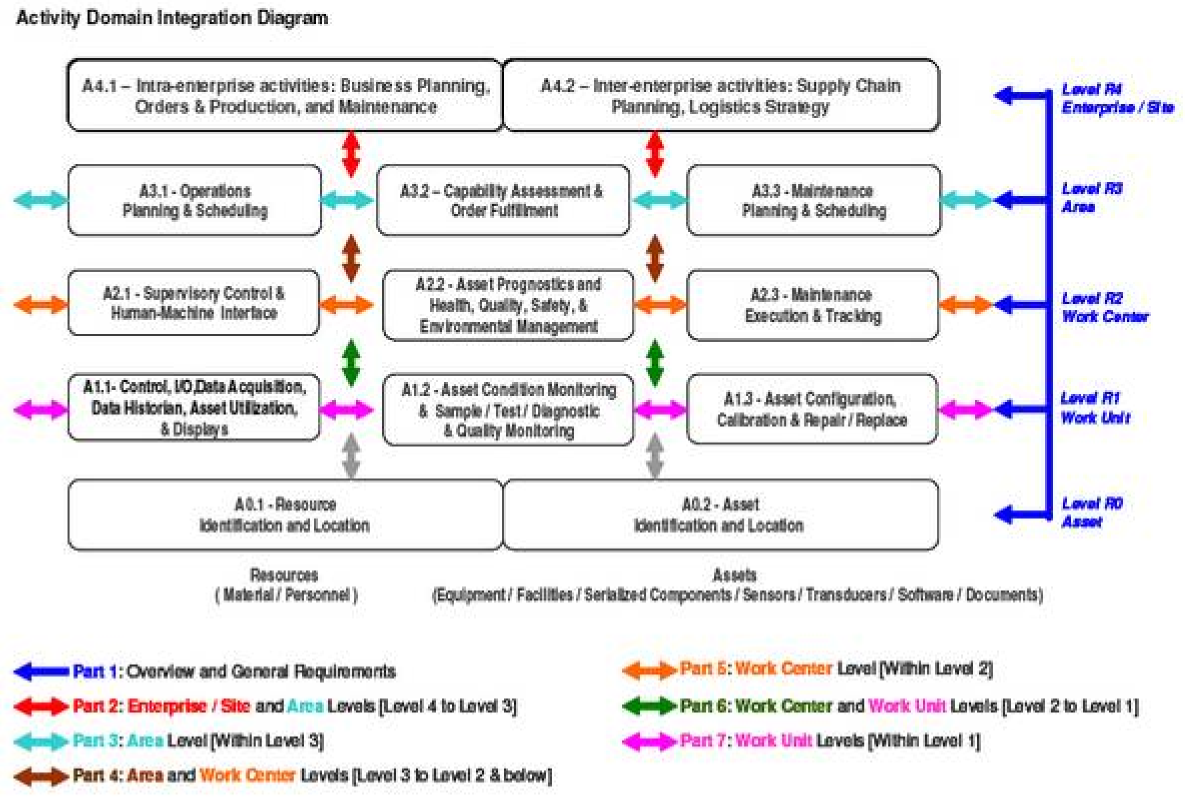

Figure 7-2 ISO 18435 activity domain integration diagram

Figure 7.2 shows how operational and maintenance activities interact with high value activities such as capability assessment, order fulfilment, asset prognostics, health, quality, safety and environmental management, asset condition monitoring and sample/test/diagnostic and quality monitoring.

7.2 Example of capability assessment in ISO 18435

This section is based on a simple use case example from [9] which illustrates the use of ISO 18435 tracking and monitoring activities. This example has several elements in common with the IMAGINE architecture v3 production flow and lifecycle in section-10.

When a customer order is received by a production environment, an Order Management activity triggers a request to a Production Planning activity. The Site & Area Applications ascertain from Production Operations and Maintenance Tracking activities on the likelihood of delivering the order on time based on the available capability and capacity of the production resources. The actors involved in the scenario are illustrated in a UML use case diagram in Figure 7.3.

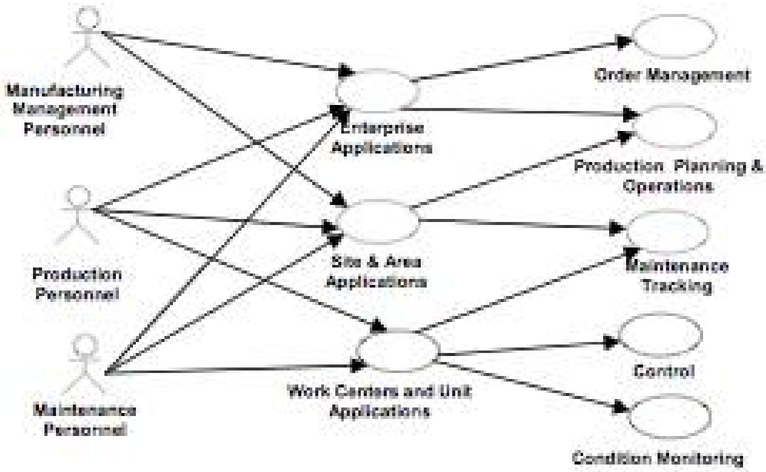

Figure 7-3 Capability assessment use case

To obtain a delivery date, the Capability Assessment & Order Fulfilment application involving the Resource Management and the Maintenance Tracking activities evaluates the likelihood of fulfilling the order based upon the expected availability of the required types of resources. This is shown in Figure 7.4. Both the Production Data Collection and the Maintenance Data Collection activities obtain status and forecasting data from the ISO-95 Level 2 Asset Prognostics and Health Assessment application and share these with the Production and Maintenance Planning & Scheduling applications.

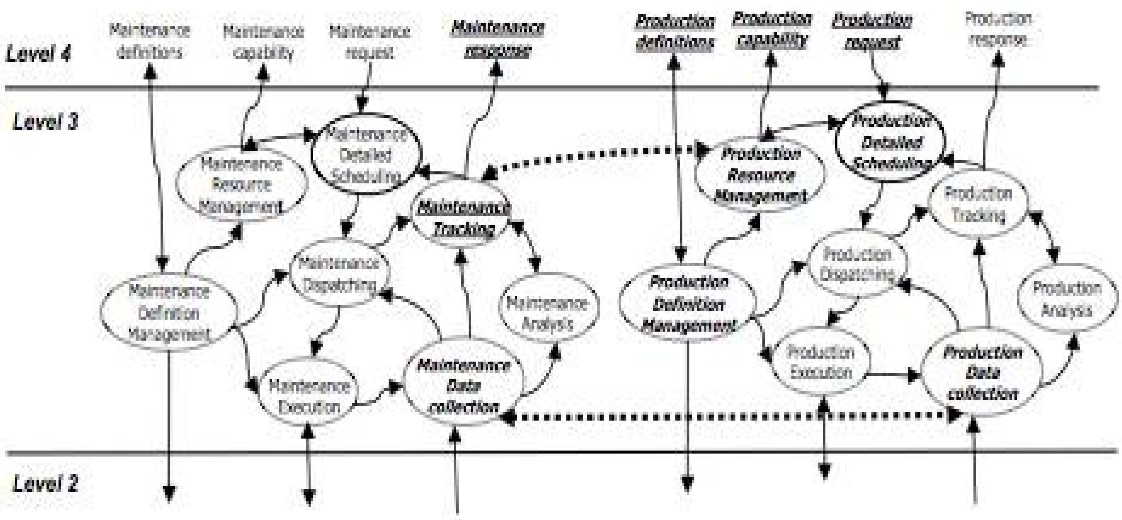

Figure 7-4 Production and maintenance application integration

The Level 3 applications of Production Operations Planning & Scheduling, Capability Assessment & Order Fulfilment and Maintenance Planning and Scheduling activities shown in Figure 7.4, can be elaborated in terms of the detailed generic ISO-95 manufacturing analytics activity model illustrated in Figure 6.1.

8 IMAGINE Monitoring and Production Analytics

8.1 IMAGINE Production Analytics

In IMAGINE manufacturers should rely on the data they need – about supply-chain metrics, production targets, or delivery schedules – and transform that data into insight to enable better production decisions. As a rule, key performance indicators from the fields of quality, service and production are compared and placed in context with one another. Key performance indicators must be defined in a clear, consistent way. This is the only way to compare different areas with one another and to transfer successful outcomes to different areas or sites.

Using automated key performance indicator systems enables development and support of so-called "goal-alignment models." This also clarifies once more how important direct feedback and gathering of key performance indicators are in an automated system. This offers users the opportunity not only to generate reports from a variety of sources, but also to integrate and correlate data from different applications and multiple existing data sources enterprise and shop-floor systems.

Recall that in IMAGINE architecture v2 process choreographies and orchestrations come adorned with KPIs (e.g., Manufacturing Lead Time, Rate of Production, Production Capacity, Order Fulfilment and Make Cycle Times as well as customer supplied KPIs). These KPIs are typically associated with the quality assurance blueprint, which will itself undergo extensions to cater for the advanced functionality of the IMAGINE architecture v3 (see section-11).

8.2 Characteristics of Event-driven Manufacturing

IMAGINE production analysis is based on the concept of Enterprise Manufacturing Intelligence (EMI). Enterprise Manufacturing Intelligence, sometimes called also Collaborative Manufacturing Intelligence, consists of the framework of integrated software and services that bring a DMN's production data from disparate sources together for reporting, analysis, visual summaries, and synchronizing data between enterprise-level and plant floor systems. Note that the role of Complex Event Processing described in section 4 suits very well to this definition of EMI: CEP can be used as the underlying technology for realizing Enterprise Manufacturing Intelligence.

EMI can be used at the plant level to improve operational visibility and collaboration and exchange of data between plant floor and enterprise systems or at the enterprise level to benchmark and visualize plant operations for operational excellence.

A common goal for using EMI is to turn plant data into useful knowledge that drives more informed business decisions. The core components of EMI include application connectors, data integration, data collection, contextualization, a data map or production model, analytics and visualization, reports or dashboards.

EMI addresses important manufacturing needs including:

- The need to rapidly address problems, isolate causes and drive resolution
- The need for collaborative process remediation among all key/critical stakeholders in a DMN
- The need to create an infrastructure to act upon real-time, event-driven data
- The need to improve accountability among the workforce to drive process improvements
- The need for visibility across the organization, to improve operations, detect variations, and monitor processes
- The need to capture information that resides in various plant/enterprise databases
- The need to maintain compliance with government, industry and corporate regulations

Manufacturers improve shop floor quality control by consistently monitoring their production processes and eliminating factors that can damage product quality. But identifying and documenting defects can be a challenging, time-consuming process. Quality managers often feel caught between a desire to take proactive measures against factors impacting production, and budgetary and time constraints that prevent them from performing statistical process control.

8.3 Conceptual View of Production Analysis in IMAGINE

Recall from deliverable D.2.2.2b that the DMN Monitoring and Management Kit is responsible for the monitoring of the execution of the DMN, the visualization of alerts and performance levels against pre-defined KPIs and thresholds, and the comparison with simulated data and root cause analysis through a user-oriented dashboard.

Figure 8.1 shows a *conceptual view* of production analysis in IMAGINE as part of architecture v3. Production monitoring and analysis consists of a collection of highly-integrated components, with a broad range of monitoring and analytics functionality, designed to analyse production KPIs and monitor production across the entire organizations and keep manufacturing processes aligned with supply chain activity. The figure also illustrates the CEP extensions to architecture v2, which are now an integral part of the IMAGINE architecture v3. The *physical view* of production analysis will be produced in the IMAGINE integrated platform, Release 3 as part of deliverable D3.2.3 where interfaces and actual data and control flows will be specified in detail.

As illustrated in Figure 8.1, the proposed architecture seamlessly integrates monitoring functionality in architecture v2 with complex event processing functionality. For providing insights and enabling reactions to potentially critical disruptions the DMN Monitoring and Management Kit in architecture v2 is extended with event processing mechanisms that intercept and identify critical situations, analyse event patterns and past solutions and trigger appropriate remedial actions by appropriately advising plant or DMN managers. To achieve this the CEP extensions capture complex events from event sources, e.g., malfunctioning equipment in the shopfloor, delays in delivery of raw materials, etc, and correlate events to identify meaningful event patterns that represent threats and assess and prioritize the probable production impact. These complex event patterns are modelled in design time and are discovered patterns on the basis of alerts, which are associated with these events, in real-time. An event history is a repository of historical event occurrences with possible remedial actions that can rectify the situation.

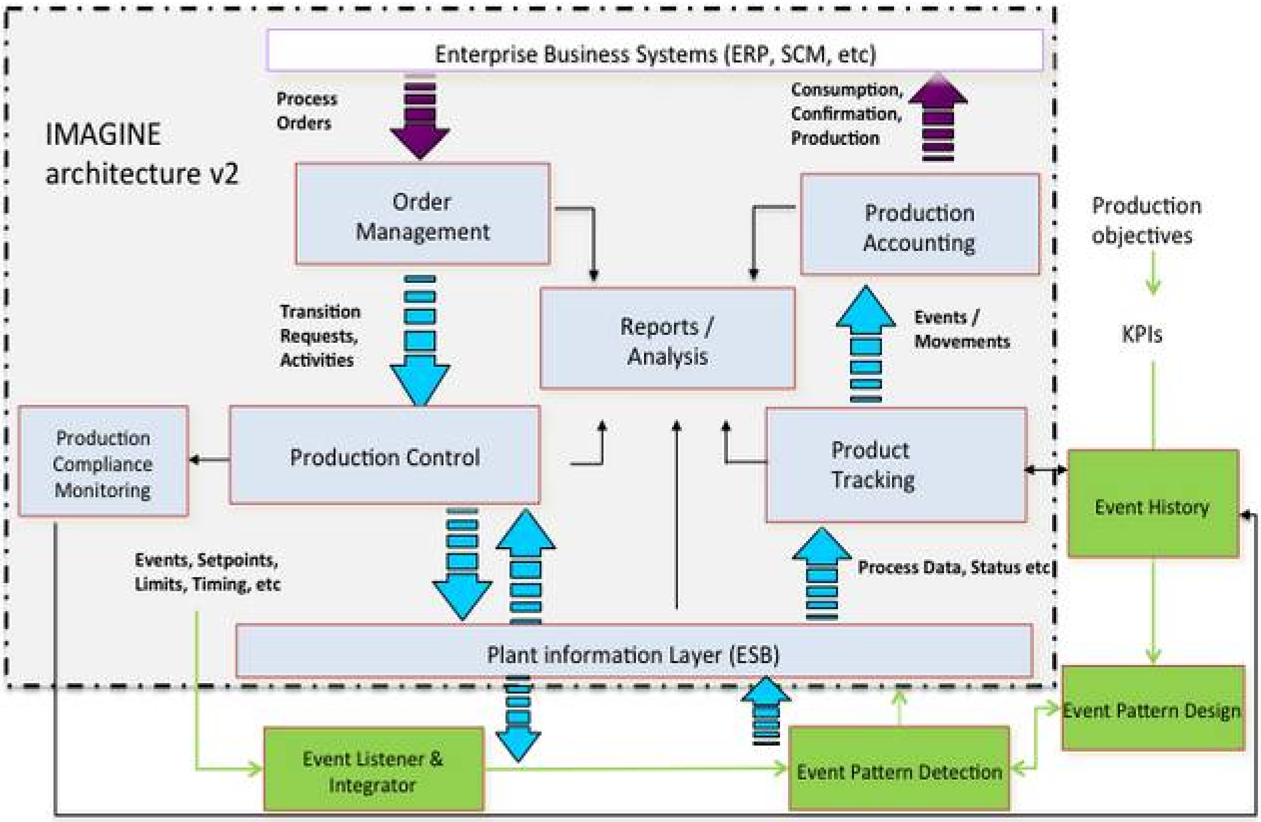

Figure 8-1 Proposed conceptual view of production analysis in IMAGINE

8.4 Functional Blocks of the Production Analysis Module

The production analysis module is an integrated set of manufacturing "intelligence" tools and components which serve as the basis for the IMAGINE architecture v3 and the design of the subsequent platform release. The production analysis module includes flexible components designed to streamline production processes and associated production metrics, networked to a choice of intuitive graphical interfaces. As shown in Figure 8.2 a comprehensive DMN monitoring and production analysis solution depends on the three functional categories: Presentation, Monitoring, and Data Access.

The production analysis and monitoring module provides dashboards of KPIs throughout the DMN based on real-time and historical plant data and other data sources. It accesses blueprint and production related repositories, user profile repositories and data sources, and includes already a set of production specific KPIs as discussed in section-3. It enables both production line and plant benchmarking, and can help DMN managers to understand where improvement measures might be necessary, and can help streamline and organize production capacity across plants.

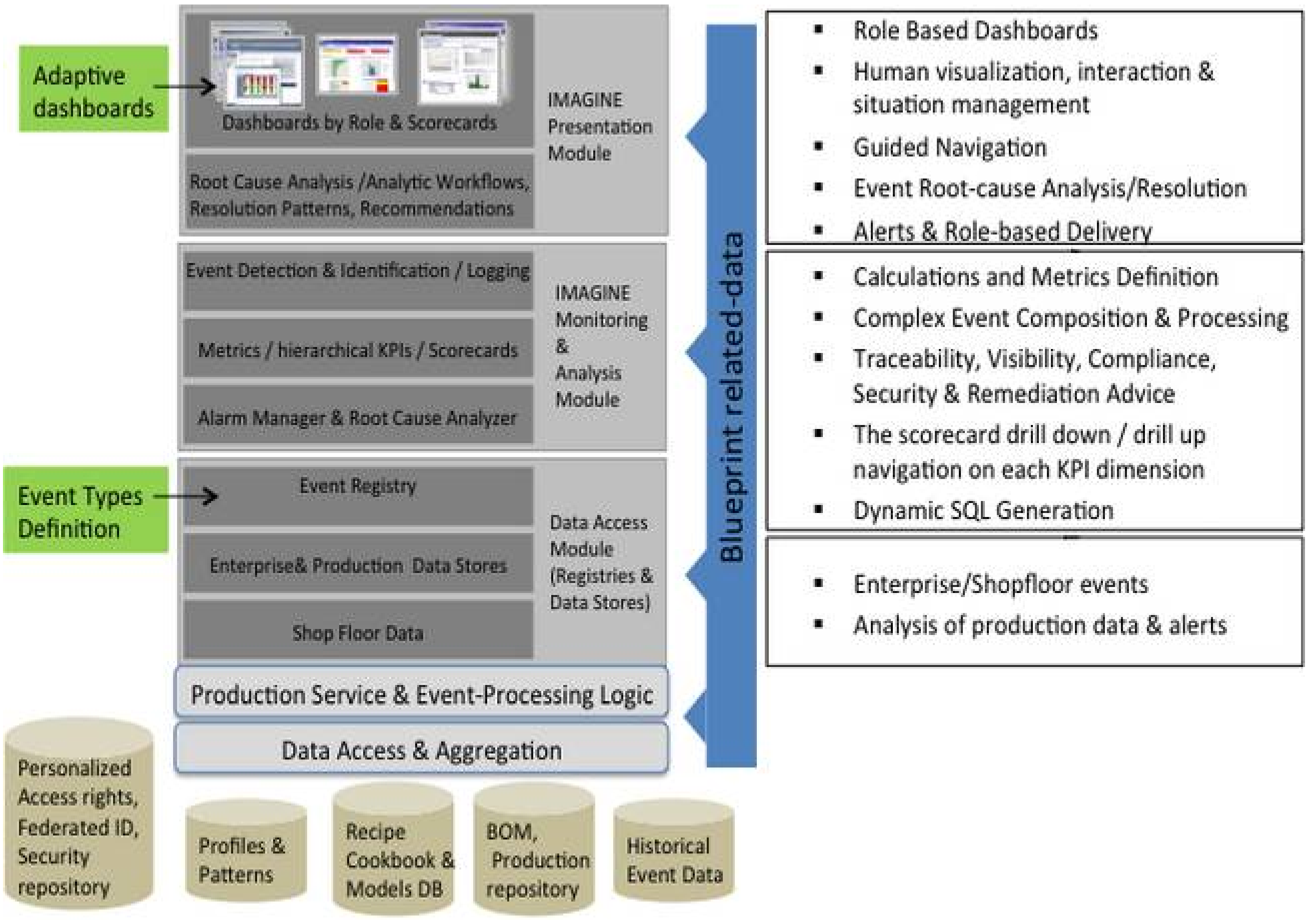

Figure 8-2 Functional categories in the DMN monitoring and production analysis solution

The presentation module is a highly visual, out-of-the box set of applications that deliver manufacturing metrics to accelerate production analysis, decisions and actions. With rapid multi-dimensional and cross-functional analysis capabilities, it provides drill-down intelligence into key performance indicators and root causes through pre-built dashboards and reports.

The presentation module includes interactive dashboards to provide real-time visibility into production operations and key risk KPIs, allowing users to quickly react to changing market conditions and make timely decisions. Dashboards can be used to acknowledge alerts generated by an event detector or to initiate actions such as root cause analysis and make recommendations for remedial action. Dashboards can be role-based and personalize metrics and alerts that are relevant to his job function (e.g., DMN manager, product quality engineer, plant manager, production manager, etc).

The production monitoring and analytics module monitors spot production performance and trends based on materials, equipment, production lines, production schedules and products. It monitors production and provides decision support to operators for correcting and improving in-process functions. These functions may be intra-operational and focus specifically on machines or equipment being monitored and controlled, as well as inter-operational, tracking the process from one operation to the next. Such monitoring and production analysis will detect and potentially compensate for current or impending plant emergencies or production problems.

The purpose of the production analysis monitoring module is to monitor all relevant processes against the specified KPIs, intercept critical events, analyse root causes, and recommend remedial action. In architecture v3 in the event that an alert is triggered during the monitoring process, a monitoring module forwards all relevant alert data to a trouble-shooting building block, which provides the end-user with the possible alternatives to solve the issue at hand. The production analysis monitoring tool drills down to the specific details of an alert and suggests resolution to a human expert by proposing appropriate actions, such as assigning alternate resources, rescheduling job operations, placing problematic jobs on hold, erroneous material movements, etc.

Finally, the data access module provides a simple data integration approach that enables existing business and manufacturing systems to work in a complementary fashion. It provides access and cross-correlation blueprint data on production processes, products KPIs and manufacturing partners, information on bill of materials and material specifications to help eliminate errors and variations in production execution. The data collected from the ESB, blueprints and other production related data sources and other modules of the i_platform must be aggregated and processed before it can be stored in a way which can later be easily accessible for querying or reporting purposes.

9 IMAGINE event-driven Reference Architecture

This section describes the reference architecture developed on the basis of complex events by project participants that can be used as standard architecture for production analysis and monitoring purposes in a large number of manufacturing environments. This architecture will constitute the basis for the IMAGINE architecture v3.

9.1 Reference Architecture for Production Analysis and Monitoring

Figure 9.1 shows a reference architecture for production analysis and monitoring developed within the IMAGINE project as part of the architecture v3. The reference architecture for production analysis and monitoring uses real-time production information, decision makers can effectively manage the order flow and production execution, tracking the transformation of products from raw materials through finished goods, and gathering real-time information on yields, quality, resource and asset management.

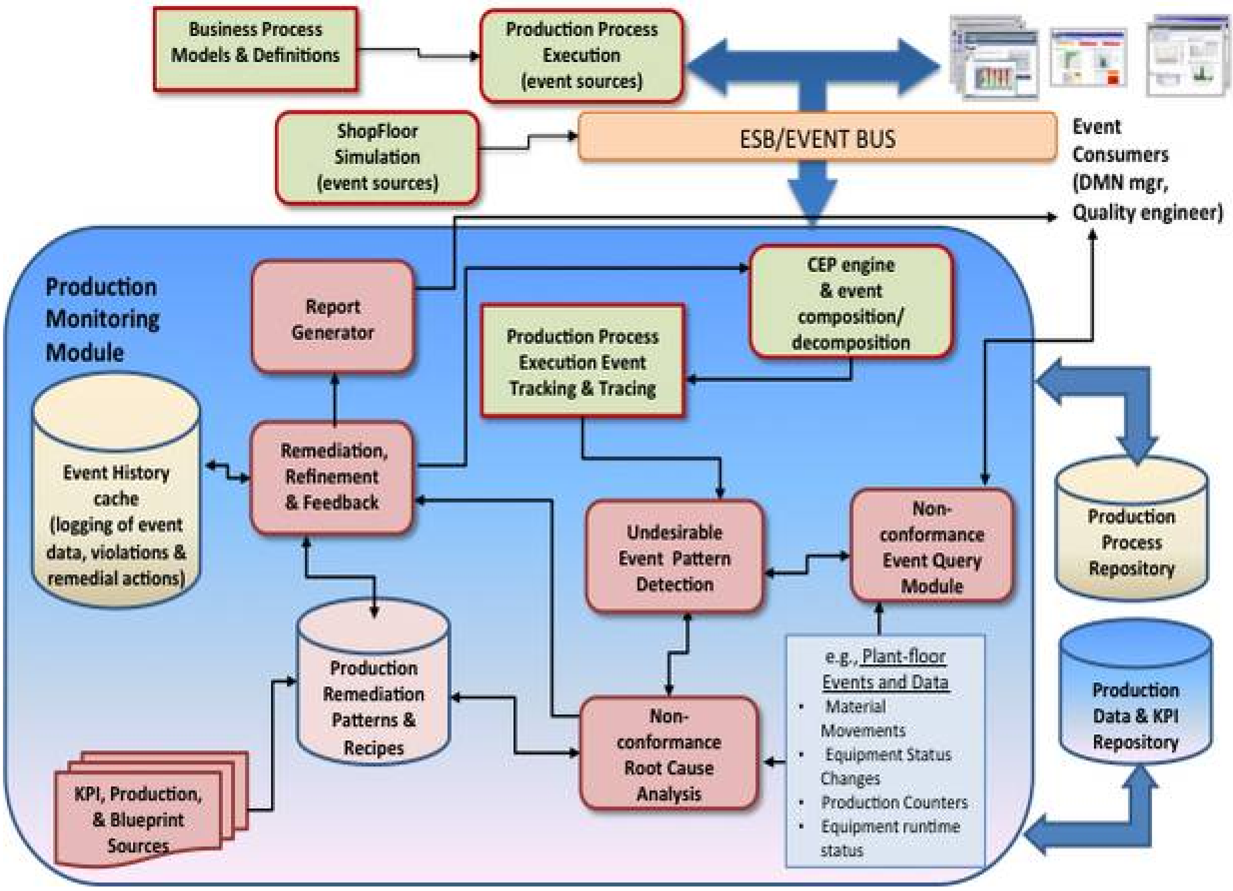

Figure 9-1 Reference architecture for production analysis and monitoring

Common production analysis activities performed on production KPIs listed in section-3 can be used to analyse production and material flow and determine crucial deviation from the planned processes.

Typical situations that may need to be analysed, may include alerts due to a physical lack of manufacturing components, partially finished assemblies from a prior operation, an inoperable machine, or in-process production quality problem.

The production monitoring and analytics reference architecture has the ability to monitor and control end-to-end production process performance and detect events that may influence it. As usual information and definitions of processes and end-to-end blueprints can be found in relevant repositories (e.g., production process repository in Figure 9.1). The production monitoring and analytics reference architecture controls order fulfilment by monitoring accurate 'planned vs. actual' production quantities. Production monitoring can lower variance in production results by improving consistency in operational activities. In doing so it analyses production process efficiency and effectiveness and aligns process improvement with enterprise goals and objectives. It also reacts to critical events affecting production performance and quality, according to event data and associated key performance indicators, which were captured during the network design phase.

Production performance and quality metrics are stored in the Quality Assurance blueprint (see deliverable D.2.2.2b) and result in notification and diagnosing performance issues, identifying deviations, trends and dynamic changes to improve production objectives and deadlines. The monitoring and production analysis module enables performance analytics of end-to-end manufacturing processes for impact analysis and production performance and quality improvement. Root cause analysis techniques are used to analyse the effects and symptoms of a faulty production process (or process segment) and trace these faults, failures and issues back to their root causes of why they eventuated and what actually caused the manufacturing problem.

In Figure 9.1 the presentation module provides real-time visibility into the full range of production processes, from production planning and setup to actual execution of operational activities as already explained in the previous section.

In the production monitoring and analytics reference architecture critical alerts and reporting of quality metrics in real time provide crucial monitoring, proactive notification, and automation capabilities that help manufacturers adapt to changing conditions and avoid alarming scenarios pertaining to production. With alerts functionality in place, they can pre-set a wide variety of benchmarks in all areas of production and protect from missing key time- or date-sensitive events or failing to respond to deviations from acceptable production levels enabling intelligent decision making and eventual corrective action.

During the execution of a production process, a traceability module listens to alerts and traces manufacturing events and steps, processes of a product or its parts before the product becomes a completed assembly. This tracking module provides an electronic record and report of both forward and backward product genealogy. Overall, this module produces an accurate and complete understanding of a product's makeup for recall needs, continuous improvement efforts and production communications. The tracking module tracks events associated with equipment used to gain a better understanding of the state of equipment, its critical process parameters while in production to create a basis for process improvements over time.

This information can also provide a unique view into the manufacturing process that is typically overlooked, including how differences between production lines can affect the output of a production run. Material lots material flows and quantities used in the production process are also tracked to verify that the correct ingredients are used in manufacturing. In addition, all events associated with actions personnel take, to promote a better understanding of their effect on finished products. In the case of an anomalous event, the tracing module records in the event history cache specific details of the incident such as the following:

- Time the anomalous (non-conformant) event occurred,
- Date/time of the anomaly,
- Level of criticality,
- Type of anomaly,
- Desired/projected value,
- Actual value.

A DMN uses information from the tracing module to identify events that lead to undesirable effects, e.g., faulty operations, steps that diverge from production plans and KPI violation, early and to quickly mitigate their effects with adequate countermeasures in such a way that event-related performance deterioration is avoided. Undesirable event patterns exhibited in the production processes can be associated with certain assignable causes for production process variation. Hence, accurate identification of various unnatural complex event patterns that signal potential production problems or disruptions can significantly narrow down the scope of possible causes that must be investigated, and speed up the troubleshooting process.

As shown in Figure 9.1, undesirable event pattern detection is a fundamental capability of advanced production monitoring applications. It is capable of identifying deviations (and disruptions) by comparing projected production plan data with actual data from production, material flows, progress of in-process work and shop-floor equipment. Undesirable event pattern detection is used in production to detect complex event patterns that may occur over a certain time period and may lead to undesirable situations affecting production performance or quality. This module uses operators to evaluate and recognize, using rules, and the occurrence of predefined complex patterns of events that could trigger undesirable production effects.

The undesirable event pattern detection module in the reference architecture detects events associated with faulty operations, steps that diverge from production plans and KPI violations that may lead to a faulty or inferior quality final product or intermediate products. It initially records in the event history cache such information as the:

- Preliminary cause of the anomalous event,
- Reason code or severity code,

and tries to identify links to standard resolution procedures for managing the anomaly based on predefined resolution rules and historical remediation data.

Notification of anomalies are automatically routed electronically to those experts who need to review and approve the continued processing or hold of the manufacturing process and review all anomaly details. Root cause analysis is then performed and remedial advice is proposed using a production remediation module.

The root cause analysis in the reference architecture in Figure 9.1 is the diagnostic part of the problem-solving process and means finding the specific source(s) that created the problem so that effective action can be taken to prevent recurrence of the situation or resolve non-critical problems before they escalate. The practice of RCA is predicated on the belief that problems are best solved by attempting to correct or eliminate root causes, as opposed to merely addressing the immediately obvious symptoms [11]. By directing corrective measures at root causes, it is hoped that the likelihood of problem recurrence will be minimized. However, it is recognized that complete prevention of recurrence by a single intervention is not always possible. Thus, RCA is often considered to be an iterative process, and is frequently viewed as a tool of continuous improvement.

A useful classification of problems is whether they are repetitive or a single event. Repetitive problems are those that occur frequently over a period of time, which allows collecting and analysing events and data related to each occurrence to detect patterns. Single event problems are those that occur at a single point in time, and require investigation of activities leading up to the event. In IMAGINE architecture v3 we will concentrate on repetitive events and potential remedies that are captured and stored in a production remediation pattern and recipe repository.

Setting critical timing triggers to problem solving is the framework to ensuring that a potentially critical event, e.g., a machine downtime event, does not go unresolved for long periods of time impacting plant efficiency. Setting time parameters is a critical element in root cause analysis. Each production operation is different so it is important to set the parameters, such as timing, links to resolution procedures and accountability, to minimize production drops and economic loss. Timing alerts (triggers) define the sense of urgency on how a production problem is addressed and what resources are required at each trigger level.

Root cause analysis is the process of drilling down from symptoms, to problem definition, to possible causes, to actual cause(s) [12]. Several common process analysis tools can be useful throughout this process, such as:

- Pareto chart: is used to analyse and graphically summarise and display categorical information on root causes to identify the major symptom contributors.
- Fishbone diagrams (Ishikawa): to depict the possible solution tree of an alarm.
- Statistical tests: While graphical tools such as run charts and histograms are good ways to analyse data, they are not as sensitive to small differences that might exist between sources of variation. Statistical tests such as the t-test, F-test, and analysis of variance (ANOVA) can detect small differences based on desired levels of confidence.

- Causal factor tree analysis: a technique based on displaying causal factors in a tree-structure such that cause-effect dependencies are clearly identified.
- 5-Whys: an iterative question-asking technique used in the analysis phase of the Six Sigma DMAIC (Define, Measure, Analyse, Improve, Control) methodology used to explore the cause-and-effect relationships underlying a particular problem [13]. The process of asking why is a combination of what occurs when a logic tree diagram is created and data is collected and analysed to support or reject each branch as contributing to the problem being solved. A pictorial 5-why diagram is used for presentation of the cause-and-effect logic that led to the final conclusion reached.
- Current Reality Tree: A method developed by Goldratt in his theory of constraints that guides an investigator to identify and relate all root causes using a cause-effect tree whose elements are bound by rules of logic. The CRT begins with a brief list of the undesirable symptoms that have been spotted, and then guides towards one or more root causes. This method is particularly powerful when the error conditions are is complex, there is no obvious link between the observed undesirable events, and a deep understanding of the root cause(s) is desired.

The root cause analysis module in IMAGINE will support a simple analysis of the anomaly situations that could rely on state of the art techniques such as, for example, Current Reality Tree techniques.

The remediation and feedback module in Figure 9.1 relies largely and refines the functionality of the troubleshooting module in architecture v2. The remediation and feedback module is a composite component that enables analysis on the logged data versus historical series and/or simulated data, and to create reports of the status of series anomalous events in a single timeframe and proposes remedial actions to qualified users through a report generator. This component relies on a history cache to retrieve historical data of anomalous event occurrences and past remedies. The remediation and feedback module also contains a simulation subcomponent, which enables the user to evaluate the predicted performances of a hypothetical DMN against real-data and trace actions down to the DMN configuration modules.

The report generator module in Figure 9.1 is responsible for the reporting capabilities of the architecture v3. The ability to create and generate reports that accurately reflect a DMN's key production performance and quality data (see section-3) is crucial as is the ability to customize these reports and display them graphically, if needed. Reports include tactically relevant KPIs based on best practices and real-world production applications and facilitate making decisions by gathering a coherent set of indicators which allow the division of production objectives and plans in individual actions down to the operational level.

Finally, the IMAGINE architecture v3 offers a rigorous standardization of interfaces and clear ISA-95 compliant structuring as well diagnostics and monitoring functions based on ISO 18435.

9.2 Simplified IMAGINE Architecture Version #3

Based on the discussion provided in the previous section we present here a simplified model of the architecture for production monitoring and analysis that will be realized as IMAGINE i_platform release 3. WE view the simplified architecture in this subsection is the initial step towards realizing the physical architecture that will serve as the basis of the design of i_platform release 3 that will be developed in WP-3 and detailed in deliverable D3.2.3.

The main reason for providing this architectural simplification is to provide a concise architecture that is close to technological stack, which distils the architecture presented in Figure 9-1. The conceptual architecture is therefore divided into separate building blocks that will be further elaborated and designed in detail and will be later implemented. Accordingly, in this section we present the variant of the reference architecture that will be fully realized in the project and validated in selected use cases.

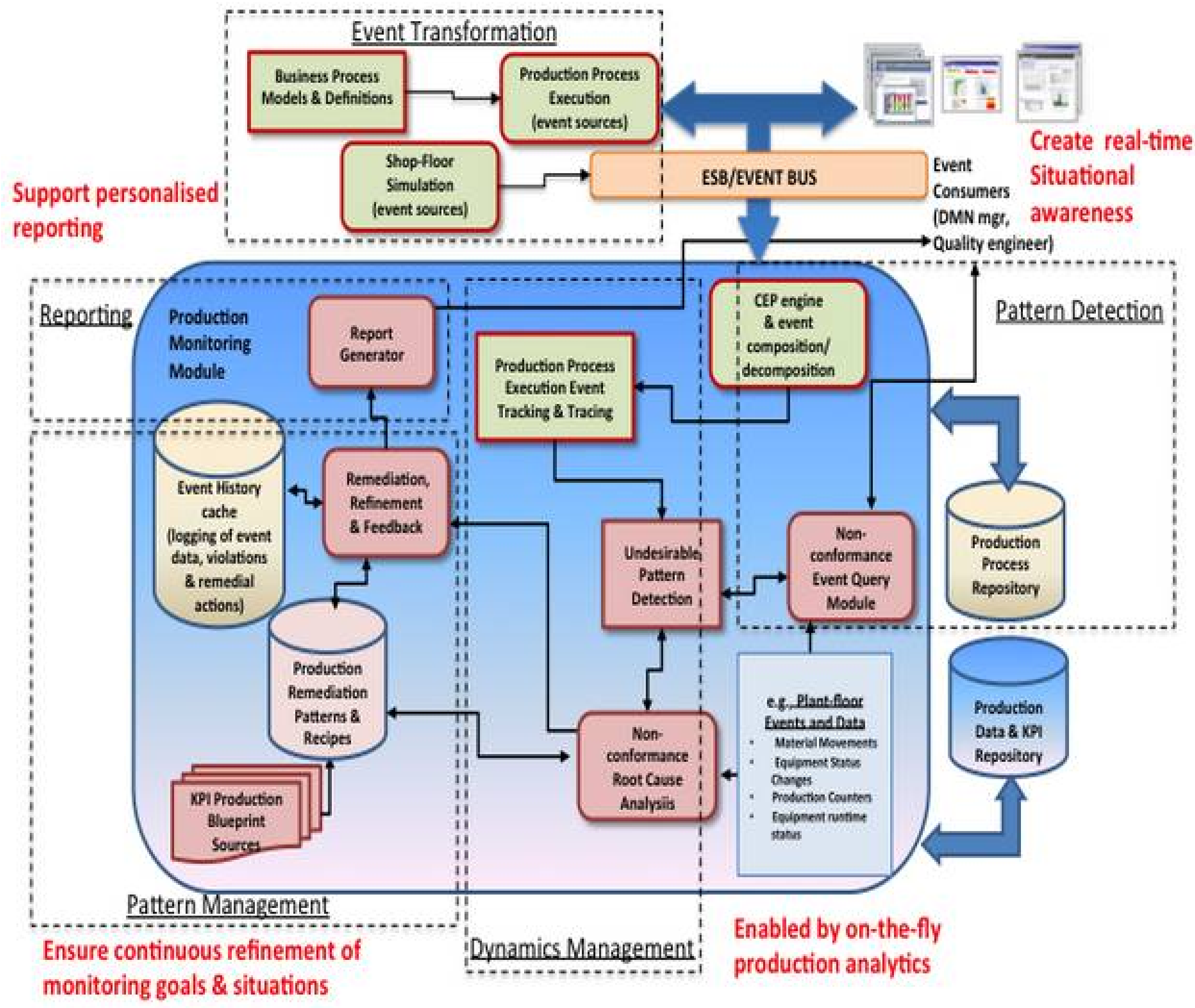

Figure 9-2 Simplified architecture for production analysis and dynamic monitoring

The main requirement for selecting a subset of the functionalities is to enable end-to-end monitoring, i.e. the complete pipeline but with less functionalities. This is the reason why we have tried to abstract from the particular functionalities presented in the reference architecture and provide functional blocks (components) that will be treated as a whole in the simplified architecture, which can be implemented in the context of the project. These blocks are related to the roles of dynamic monitoring and production analytics presented in section 2:

- to support definition and modelling the situations of interest,
- to enable monitoring and the detection of the relevant situations,
- to ensure continual refinement of the situations that should be detected/monitored and
- to sense dynamic changes in the input data and detect exceptional situations.

Figure 9.2 presents this simplified architecture, which serves as the IMAGINE architecture v3. In the following we present the short description of all of the functional blocks in the simplified IMAGINE architecture v3. Note that detailed descriptions of the software components related to these blocks can be found in the deliverable D8.1.

1. Event transformation
   It is related to defining and preparing relevant event sources required for monitoring and production analysis. Definition consists of modelling event types which correspond to each event sources and the preparation is related to the software adaptors that enable the transformation of the signals sensed from event sources in the proper format.

2. Pattern detection
   This block enables the detection of the patterns (situation of interests). This is "classical" pattern recognition task, realized by a CEP engine. It results in creating real-time situational awareness (in the given manufacturing context).

3. Pattern management
   It is related to ensuring continuous refinement of the monitoring goals & situations. The block is very relevant for dynamic environments, like manufacturing, where plenty of factors can influence business processes (production efficiency and quality). This is an advanced processing block that is based on different methods for extracting knowledge from operative data and the usage data in order to refine the situations that should be detected and monitored.

4. Reporting
   This block is related to supporting personalized and adaptive presentation of the results from the Pattern detection process. The block will be specified with more details once the requirements for presenting/delivering information are clarified in use cases.

5. Management of the dynamics
   This is the most crucial processing block in the dynamic management process. It is related to sensing the dynamic changes in the input streams in order to detect situations which might

be exceptional, unusual, or misleading. Moreover, this block is responsible for detecting the business opportunities as well.

In order to present the processing meta-layer in a more understandable way, we provide a high-level mapping between blocks, as illustrated in Figure 9-3.

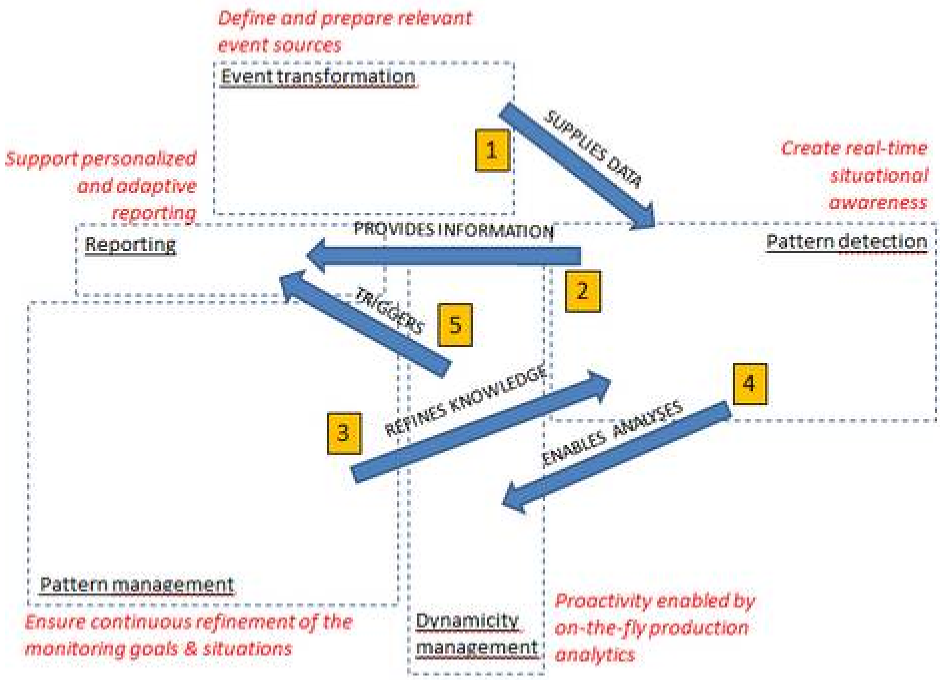

Figure 9-3 High-level relations within simplified architecture

As presented in the figure above, each of the blocks has an important role in the processing pipeline (end-to-end processing), as stated in the above mentioned requirement for the simplified architecture. In the following we describe these roles briefly.

1. Event transformation supplies the data to pattern detection: In this way we ensure the continuity of the data injected in the processing pipeline
2. Pattern detection provides the relevant information to Reporting: This relation ensures a proper presentation of the complex results of the detection process. Moreover, the reporting is personalized and adaptive.
3. Pattern management refines the knowledge that is used for defining and detecting relevant situations. This process is continual, i.e., the system is continuously improving the quality of the monitoring patterns.
4. Pattern detection enables analyses for the Management of the dynamics in a DMN: This is the most difficult relation since the dynamics has to be sensed in the most efficient way in order to retain real-time performances of the system. It requires a dynamic interaction between the pattern detection process and the process of defining anomalies and unusual situations (on the fly).

5. Management of dynamics triggers Reporting: In order to create awareness about unusual/exceptional situations an efficient communication of triggers and a proper visualization of their effects must be provided.

Note that the deliverable D8.1 contains more details about the software realization of phases in the presented dynamic monitoring.

10 IMAGINE Event-driven Production Flow and Lifecycle

This section describes the production-oriented flow introduced in previous deliverables in the context of the IMAGINE architecture v3. The main differences are expended functionality to the addition of complex production events.

10.1 DMN Production Activities

Figure 10.1 is an extension of Figure 7.2 in deliverable D.2.2.2b, which depicts the production activities and elements associated with a production in a DMN. Figure 10.1 in particular illustrates the event-based functionality associated with the production flow according to the KPIs introduced in section-3, the production analytics functionality and the operational aspects of the IMAGINE architecture v3 introduced in the previous section. This contribution is highlighted in the figure below.

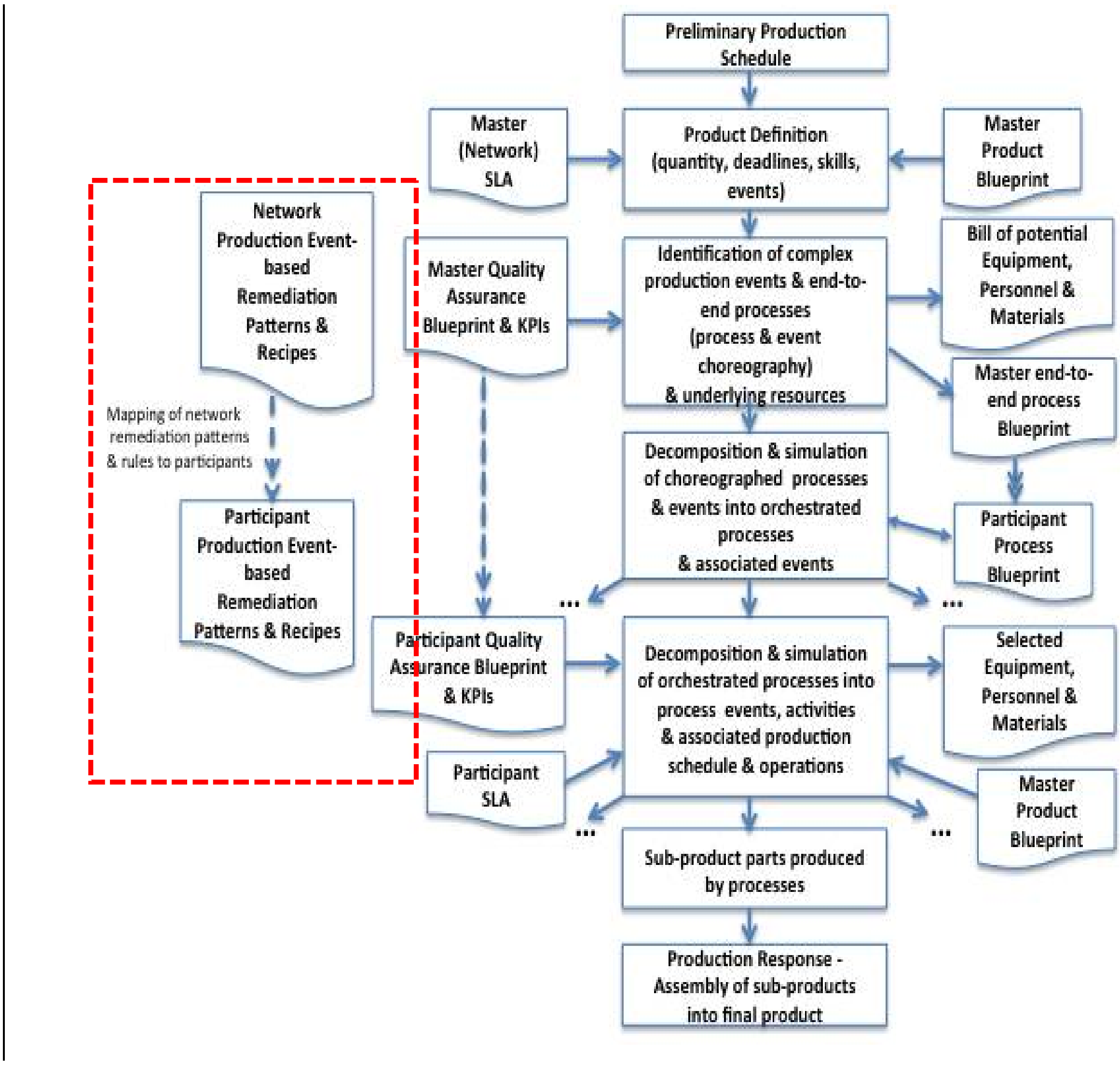

Figure 10-1 DMN production activities, events and data objects

As with the architecture v2, DMN design in architecture v3 follows a top-down decomposition approach. This is shown in Figure 10.1 where production processes are successively decomposed from the level of choreographed end-to-end processes down to the level of process activities. Recall from architecture v2 that a choreographed process is a standard end-to-end process spanning various DMN participants producing a specific product (e.g., a car door). Choreographed processes are decomposed into standard orchestrated processes, such as Car_Door_Welding, Car_Door_Painting, and Car_Door_Assembly performed by specific DMN partners. Orchestrated processes can be further decomposed into process activities. A process activity in Figure 10.1 is the lowest part of the production process that is linked with a machine/equipment (operation-machine combination). For example, Car_Door_Welding is decomposed into process activities such as edge-wrapping, laser trimming, ultrasonic welding, and hot wire cladding.

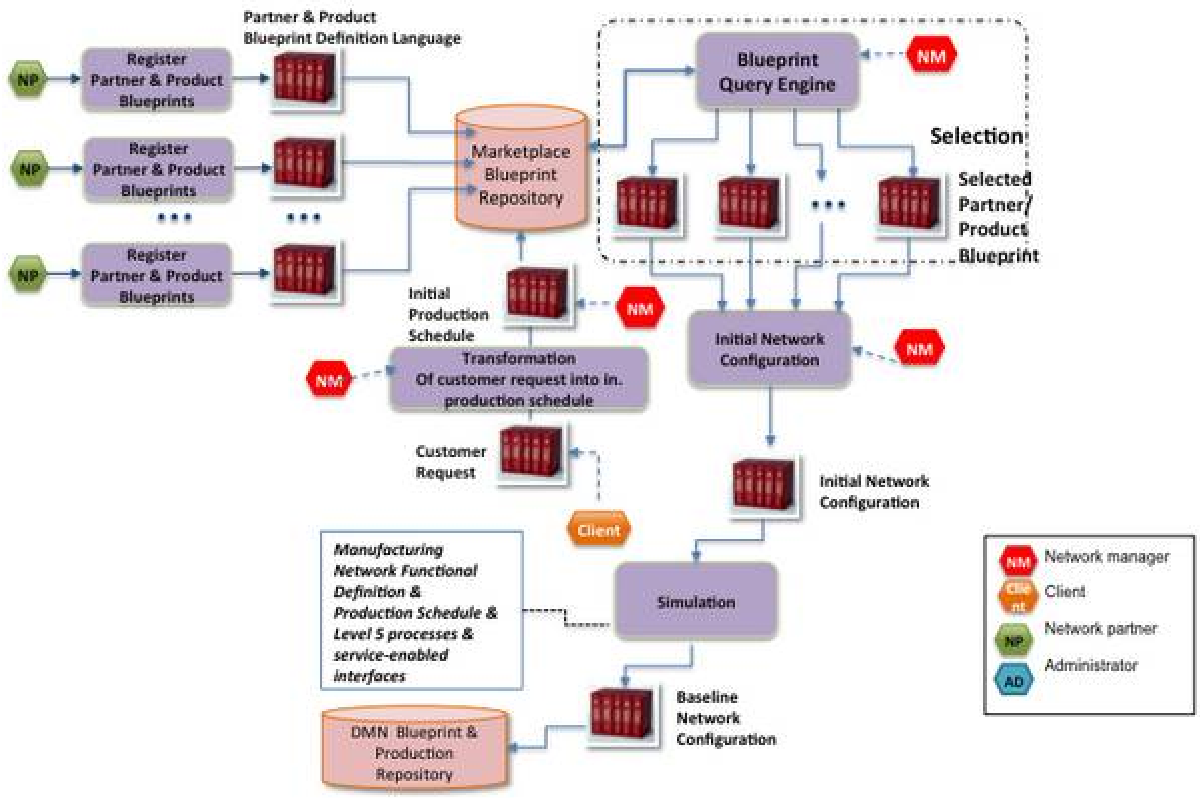

Figure 10-2 Overview of production flow activities during on-boarding and configuration

Figure 10.1 also contains critical events associated with the choreographed and orchestrated processes. These events are called network production events and participant events, respectively. Critical network events in a choreographed process may signify the significant events that may signify production delays or quality problems with the overall production. For instance, in the case of manufacturing a car door that may signify problems with major activities such as faulty Car_Door_Welding, inferior Car_Door_Painting, or problems with the Car_Door_Assembly. Critical participant events are usually associated with orchestrated processes and may signify problems with activities and associated events within the orchestrated processes themselves, e.g., the outer door panel and the doorframe are not perfectly welded together or the laser penetration depth into the sheets is not entirely correct.

10.2 DMN Production Lifecycle

Figure 10.2 shows the production flow activities during the phases of on-boarding and DMN configuration. These activities are identical to those that are part of architecture v2 and were originally explained in detail in deliverable D2.2.2a and Figure 3.2 in particular.

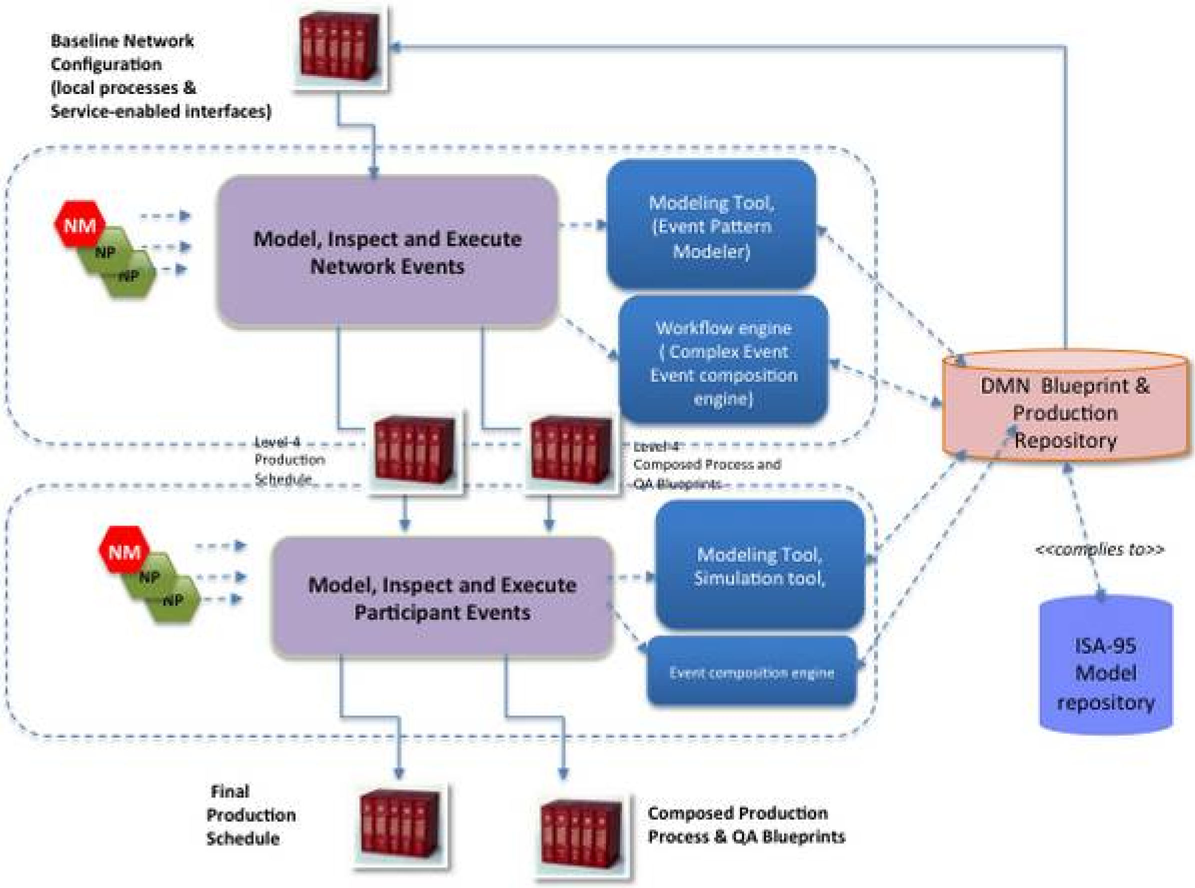

Figure 10-3 DMN design phase for architecture v3

As already mentioned in deliverable D2.2.2a purpose of the DMN design phase is to chart the DMN and its production processes as a series of workflows and analyse and map the dependencies between these workflows. The resulting enterprise and production processes, along with their associated dependencies and timing, constitutes a working canvas for an entire DMN. In addition its purpose is to produce a detailed network production schedule.

In architecture v2, the DMN design phase focuses mainly on process-oriented manufacturing activities management and applies a methodology for viewing an end-to-end manufacturing process with a view to optimizing their efficiency. Its purpose is to align business and plant processes and to streamline shop-floor operations.

Figure 10.3 illustrates the simplified design phase for the DMN with emphasis on complex event processing functionality. This figure shows that the major differences with architecture v2 and the DMN design phase in deliverable D2.2.2a (and Figure 3.5) is that the process definitions and deployments in architecture v2 have been extended with process simulations and association of critical anomalous events for the entire DMN and for DMN participants.

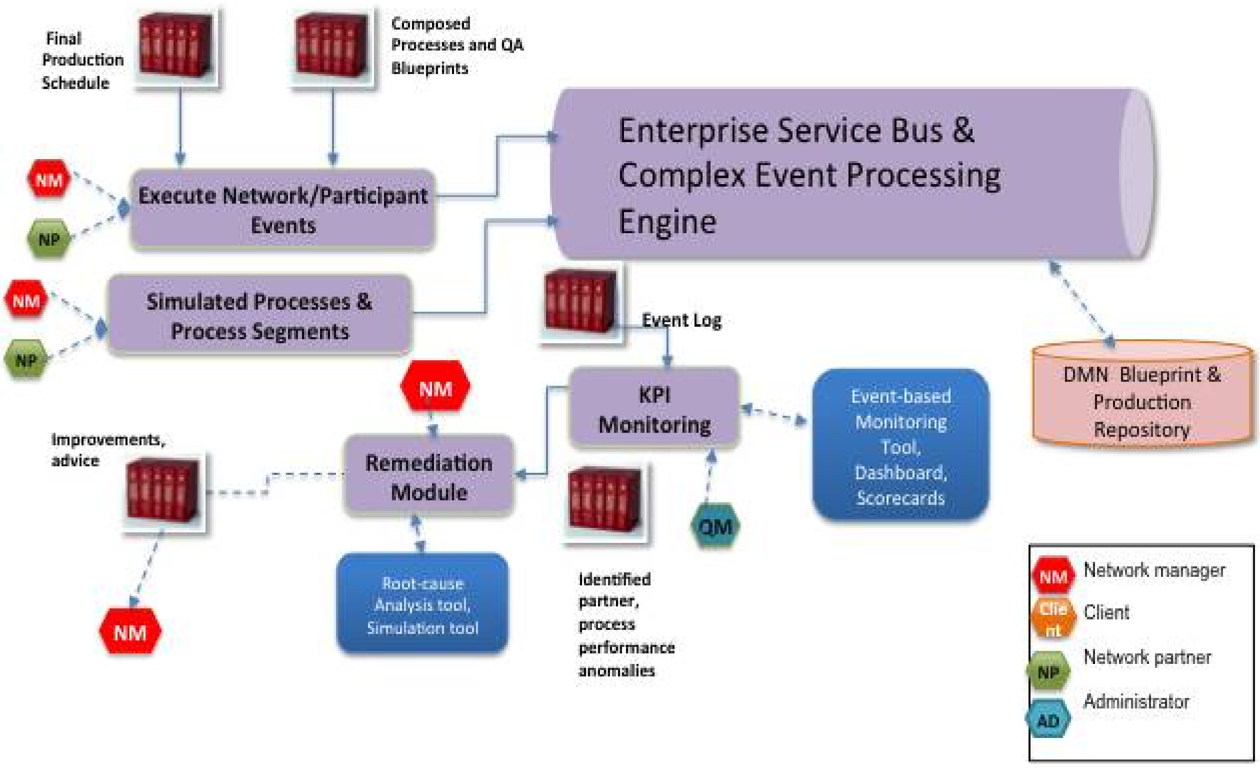

Figure 10-4 DMN execution and the monitoring of production KPIs

As already mentioned in deliverable D2.2.2a the execution and monitoring phase involves the realization and actual deployment of a manufacturing network and its processes and the monitoring of its execution, e.g., abnormal conditions, machine failures or KPI deviations. Its aim is to monitor production processes and provide decision support facilities to operators for correcting and improving process activities. Figure 10.4 depicts this situation for architecture v3. The major difference between architecture v2 and the monitoring block diagram in Figure 3.6 in deliverable D2.2.2a is that the execution phase in the architecture is concentrating on simulated production processes. These processes have been extended with critical events signifying anomalies either at the network or participant level. Such events are executed by the CEP engine, which extends the functionality of the Enterprise Processing Bus (ESB).

11 Extension to Quality Assurance Blueprints

11.1 Extended Quality Assurance Blueprint model

This section provides an extension to the Quality Assurance Blueprints' model, which is presented in the Architecture of IMAGINE Platform (D2.2.2) and in the Detailed Design of IMAGINE Platform (D3.1.1). The extension to the Quality Assurance Blueprints aims to provide enhanced insight into the monitoring of Dynamic Manufacturing Networks by supporting the production measurements as described in section 3. This extension enhances the IMAGINE blueprint model with additional information that are required in order to provide targeted support related to production measurements. This extension is implemented by the introduction of the ProductionMeasurementTerm Class into the Participant Quality Assurance Blueprint and the annotation of the Participant Quality Assurance Blueprint with the relationships that link to the Production Measurements.

The provided extension leverages the IMAGINE blueprint model extensible and customizable architecture, it is able to annotate the existing blueprint models. The extended version of the blueprint model with the Production Measurement is backwards compliant to the un-extended Quality Assurance Blueprints model and fully compliant to the overall IMAGINE Architecture, and thus, design and implementation. Due to this fact the IMAGINE Platform will be able to accept both extended, and un-extended versions of the Quality Assurance Blueprint.

The added relationships and classes are able to implement the Production Measurements required to enable performance measurement in accordance to the philosophy of the IT Performance Management Group (ITPMG) [2].

11.2 Production Measurement Terms

The basic class that is being used in order to enable the measurement of production in accordance with the IMAGINE viewpoint is the Metric class. The Metric class provides metadata for the real time values that a company is able to provide during the execution time of a DMN. The metric class describes in detail the expected minimum, maximum and average values for a particular metric as well as the precise unit of measurement. The Metric class is abstract and is never instantiated directly. Each instance of the Metric class should be specifically linked to a particular resource that the Supplier can make available for DMN manufacturing. For this reason the Metric class has four distinct subclasses, one for each of the ISA-95 originating resource classes that are available in IMAGINE Platform, which are the Skills, Materials, Processes and Equipment. Namely the SkillMetric, MaterialMetric, ProcessMetric and EquipmentMetric subclasses of class Metric. Each instance of the Metric class should be specifically linked to a particular resource that the Supplier can make available for DMN manufacturing. The instances of these classes are linked to the participant Quality Assurance blueprint and describe the real time values the companies can provide during execution time. With the extension of the Quality Assurance Blueprint their usage is extended to provide the real time values needed for the calculation of the production measurements in conjuction with the introduced ProductionMeasurementTerm class.

A ProductionMeasurementTerm class instance is always linked to one of the four subclasses instances, so essentially every ProductionMeasurementTerm class instance is also linked to a specific company resource. The ProductionMeasurementTerm class also contains a coefficient, which indicates the weight needed in order to calculate the production measurements. The ProductionMeasurementTerm instances that are used to calculate each of the production measurements described in section 3. In particular the ProductionMeasurementTerm needed to calculate the Perfect Order Fulfilment, the Production Efficiency, the Production Quality and the Production Equipment Effectiveness are linked with the appropriate relationships in the blueprint model. By utilizing the annotation of the production measurement relationship as well as the resources linked to the metric the IMAGINE Platform has all the required information to calculate the production measurements for each of the provided resources. The calculated production measurements at individual resource level can be then brought up in DMN level by fusing together the production measurements.

Figure 11.1 highlights the Quality Assurance Blueprint extension and provides a graphical overview of the aforementioned description. The provided extended blueprint schema is flexible and allows also alternative definition of production measurements by customization. The extended Quality Assurance Blueprint offers a useful mechanism for the evaluation of complex KPIs on DMN and Partner level that can be leveraged for the effective KPI monitoring of running DMNs.

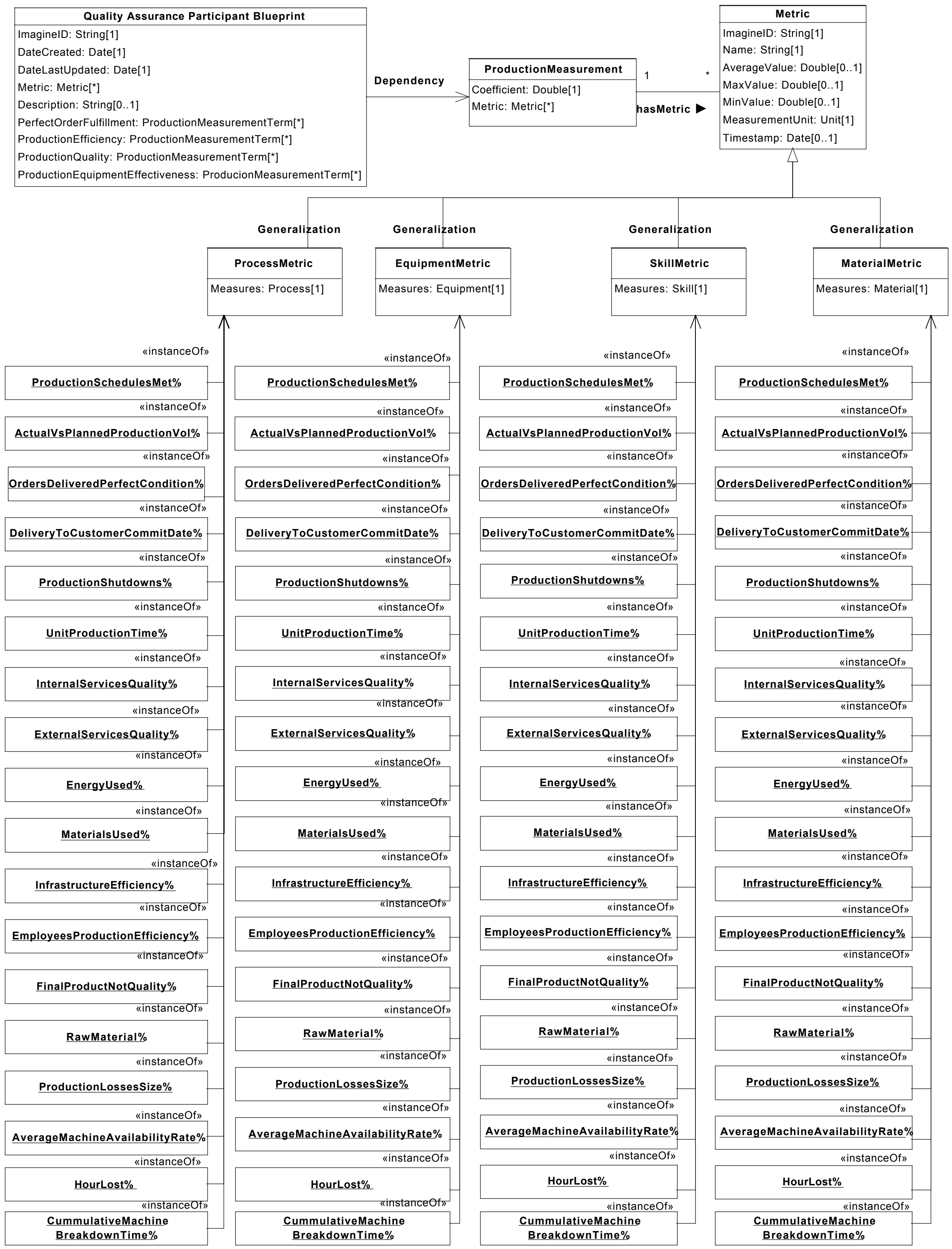

Figure 11-1 Production Measurements extension of Participant Quality Assurance Blueprint

12 Summary

This deliverable has proposed a holistic architectural approach vis-à-vis production analytics and production monitoring on the basis of complex production events. The deliverable proposed a reference architecture (viz. the IMAGINE architecture version 3) that extends the IMAGINE architecture version 2 by seeding complex events processing technology into the monitoring, analytics and alerting operations in production environments. Complex events processing combines multiple events to generate an alert, giving DMNs the ability to make correlations between different production events to detect that something is going wrong in production – even if it is not apparent at first glance.

The reference architecture presented in this deliverable (Figure 9.1) identifies the set of generic components recommended for use in production analytics and production monitoring. It contains the basic principles and functionality that apply to a variety of manufacturing environments, regardless of their size, application domain and mission. This conceptual architecture provides a generic framework and set of generic principles and functionality which can apply to all aspects of smart manufacturing (especially Distributed Manufacturing Networks). The reference architecture serves as the basis for customization and construction of robust monitoring and analytics in production environments that provide higher order diagnostics, monitoring and troubleshooting in a variety of manufacturing domains, such as automotive, furniture, electronics, and so on.

The deliverable also presented a simplified model of the reference architecture for production monitoring and analysis that will be later realized as the IMAGINE i_platform release 3. The main reason for providing this architectural simplification (see Figures 9.2 and 9.3) is to provide a concise architecture that distils the architecture presented in Figure 9-1 divides it into separate building blocks that will be further elaborated, validated in selected use cases, designed in detail and implemented. The simplified architecture proposed in this deliverable contains core building blocks for design and development and is considered as the initial step towards realizing the physical architecture that will serve as the basis of the detailed design of i_platform release 3. The simplified architecture will be analysed and evaluated in WPs 3 and 8 to decide to which extend its core aspects can be implemented as part of the IMAGINE framework release 3. Note that the detailed design of the i_platform release 3 will be conducted WP-3 and will be detailed in deliverable D3.2.3.

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