# Event-Driven Business Intelligence Architecture for Real-Time Process Execution in Supply Chains

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**Abstract.** This paper gives an insight perspective for developing a business intelligence architecture to satisfy permanently growing controlling requirements in complex distribution networks. Supply Chain Management (SCM), as a part of management science concerning intelligent synchronization of supply and demand, is the basis for the development of flexible, proactive and adaptive real-time information systems, called Operational Business Intelligence (OpBI) systems, which offer a significant support for decision making on operational level. Application scenarios including concrete decision-problems are analyzed regarding system implementation and in consideration of supply chain performance. The conclusion reflects the development process in order to allow a foresight.

**Keywords:** Operational Business Intelligence, Supply Chain Management, Event-Driven Architecture, Radio Frequency Identification.

## 1 Introduction

Since the last decades the term *logistic efficiency* is a keyword in organizations aspiring cost-leadership. But in the sense of global and dynamic markets as well as a result of growing customer demands and shortened product life cycles, concentration on the efficiency perspective only has to be marked as inadequate. The constantly growing complexity asks for a trade off between the cost-leadership paradigm and required effectiveness. Claims for flexibility, reactivity and reliability encourage the change to process-oriented system thinking and flat organization hierarchies. As a result, not only companies but value networks compete against each other [4].

The main objective of this paper is to point out an intersectoral business intelligence architecture to satisfy permanently growing controlling requirements in complex distribution networks. Supply Chain Management (SCM), as a part of management

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science concerning intelligent synchronization of supply and demand, is the basis of the development of flexible, proactive and adaptive real-time information systems called Operational Business Intelligence (OpBI) systems, which offer a significant support for decision making on operational level. Current processes are controlled on the basis of analytical information and strategic objectives either semi-or fully automated.

The conceptual design of the information system results from a functional perspective. In the following chapter the theoretical basis, concerning SCM in general and its related performance measures, will be exposed. After a theoretical foundation of the term OpBI, the system components are specified consecutively. The following explanations will be related to the entire architecture. Application scenarios including concrete decision-problems are analyzed regarding system implementation and in consideration of supply chain performance. Thus, the research contribution of this paper is a conceptual business intelligence architecture for process execution, which integrates different components identified in a literature review and satisfies the requirements of the SCM use case scenario.

## 2 Use Case for Supply Chain Logistics

At the beginning of the development process possible application scenarios within the multifunctional SCM paradigm have to be extracted. It should be a general intersectoral application scenario and should fit into general logistic trends. Subsequently, the classification criteria of the supply chain perspective, infrastructure as well as the structure of commodities and distribution strategies will be differentiated. Considering trends concerning vendor independent planning and control of distributive supply chain systems the focus has to be on the outbound logistic service provider's perspective, who takes over the distribution- and redistribution functions between manufacturers and retailers. The logistic service provider is a system server (Third Party Logistics, 3PL). This means that the service provider is responsible for outbound logistics' planning and control without retaining further subcontractors. From now on it is called a network integrator. Practical examples are provided by courier-, express- and package service providers, which have expanded in the past into the sector of industrial contract logistics and value added logistics.

Due to simplification only double-staged local or regional supply chains are considered, which means that three distributive network stages appear: manufacturer, network integrator and retailer [11]. The network integrator has to control the convergent transport flows originating from the manufacturers, as well as the divergent transport flows to the retailers. Therefore, the system is comparable to a hub-and-spoke network without direct transport. Stock levels are only taken into consideration by the network integrator and retailers depending on the structure of commodities and implicit distribution strategies. Concerning capital expenditure the network integrator possesses resources concerning vehicle fleet, storage equipment and information technology. Because the following architecture focuses on a neutral network integrator it allows a comprehensive integration of different structures of commodities and distribution strategies. From a strategic perspective efficiency is achieved by means of forecasting and optimal lot sizing. Moreover, reactivity and flexibility are provided within make-to-order (m-t-o) paradigms.

Subsequently, with regard to the derived objectives of the OpBI system the focus is put on the control processes of the network integrator. A distribution center has to consider internal procurement processes and supply processes as well as retour processes within make-to-order and make-to-stock (m-t-s) paradigms. Stock keeping, as being a characteristic function, is taken into consideration within procurement processes referring to the reference processes of the Supply Chain Operation Reference Model (SCOR). Intra- and inter-organizational planning processes, which may determine order policies between network actors temporally, will only be considered as a framework of operational control processes. This means that results from tactical demand and inventory planning only serve as restrictions, thresholds or control variables of the operational information system.

## 3 Operational Business Intelligence

The explanation below provides a theoretical classification of the OpBI approach. Concerning enhancements of classical Business Intelligence (BI) approaches precise system requirements can be derived. Referring to the consensus parts of former definitions, OpBI can be summarized as an approach for fast, flexible and adaptive process control and decision support on the basis of analytical BI methods [5,15]. Therefore, OpBI follows recent trends in operational and organizational structures of companies. In doing so, decision making is simplified or automated at the operational level addressing a broad range of users. OpBI is directly connected to many existing approaches. Regarding operational process control it can be linked to Business Activity Monitoring (BAM) as well as Business Performance Management (BPM), which can be seen as requirements in order to monitor and to control processes continuously. Supply Chain Event Management (SCEM) is an approach to integrate planning and executive operations by identification of events causing disturbance [1,11]. In this context, OpBI can be seen as a technical enabler or implementation of a proactive real-time BPM- or SCEM-Paradigm [7].

Recommendations of integrated operational and analytical functions, which have been published, use concepts like real-time data warehousing [2] or active data warehousing [10,13]. Both approaches focus on a reduced decision-action time in order to enhance the decision's business value. Latencies cover a period between event appearance and reaction. This contains data latency, analytical latency and decision latency [10]. While real-time data warehousing concepts try to improve analytical systems' actuality by accelerating information system's loading time, the active data warehousing concepts focus on an improvement of the ability to give feedback to actions directly. This implies closed loop data processing between operational and analytical systems.

Moreover, OpBI can be seen as a concept that combines important topics covered by the mentioned approaches. This means Operational BI implicates process transparency, synchronization of strategic and operational control quantities, shortening of latency time as well as real-time data processing and not least the feedback of operational systems and decision makers. OpBI denotes an explicit change of traditional BI located at tactical level. Within this focus, at least daily data uploads from operational to analytical systems took place [8]. As a result decision making support or process control could only occur reactively on the basis of analytical aggregated information.

To achieve a proactive connection between analytical methods and operational process control regarding predestinated aims, OpBI has to close the time lags between event identification and reaction. Moreover, OpBI has to bridge the information gap between operational, tactical and strategic level. In the following these challenges, which determine the structure and effectiveness of an OpBI system, are described. Performance in the context of logistics is difficult to grasp as a theoretical construct including its cause-and-effect connections. As a result, objectives on the strategic, tactical and operational levels diverge in practice. Control approaches, which allow a holistic view of business environments, e.g. Balanced Scorecards, are only sufficient for a performance definition [14]. A proactive, semi- or fully automated process control needs predefined logical causalities concerning performance attributes and performance indicators, in order to control real-time events and problems precisely. Therefore, decision artifacts at the lowest level of granularity are focused in contrast to classical BI. OpBI has to guarantee a continuous congruency regarding physical decision artifacts and virtual process information.

A coupling of analytical and operational real-time systems implicates a bridging of existing time gaps related to latency [12]. Concerning existing decentralized operational system environments, especially in the context of SCM, the biggest challenge for an OpBI system is to minimize the time lag. The classical approach to update data daily only allows ex-post analysis. While operational dashboards and composite applications already constitute first steps concerning real-time decision support, analytical event-controlled platforms are regarded as promising proactive control instruments.

# 4 Concept of Operational Business Intelligence for Increasing Supply Chain Performance

The synchronization of operational and strategic control quantities within a performance measurement system represents a specific perspective for the implementation of an OpBI system regarding SCM. From a network integrator's perspective standardization of performance measurement has to be preferred, because it can be adopted beyond business boundaries. The SCOR model being a normative control model offers a complete transparency of value adding processes and a standardized framework for the definition of causalities concerning strategic objectives. In doing so, performance indicators from operational systems as well as from applications regarding event registration will be extracted, transformed and enhanced. Afterwards they will be loaded into a data mart consisting of the SCOR performance indicators on the basis of the core data warehouse.

## 4.1 Operational Business Intelligence Architecture for Supply Chain Management

The subsystems of an OpBI architecture will be combined with the classical BI architecture. Thereby, connections and interdependencies of subsystems are described using a five layer architecture, consisting of the following layers data sources, data acquisition, data storage, data provision and data analysis, as well as data presentation. The data source layer offers event-based data of control processes from operational transaction systems, e.g. directly from the central application regarding Electronic Product

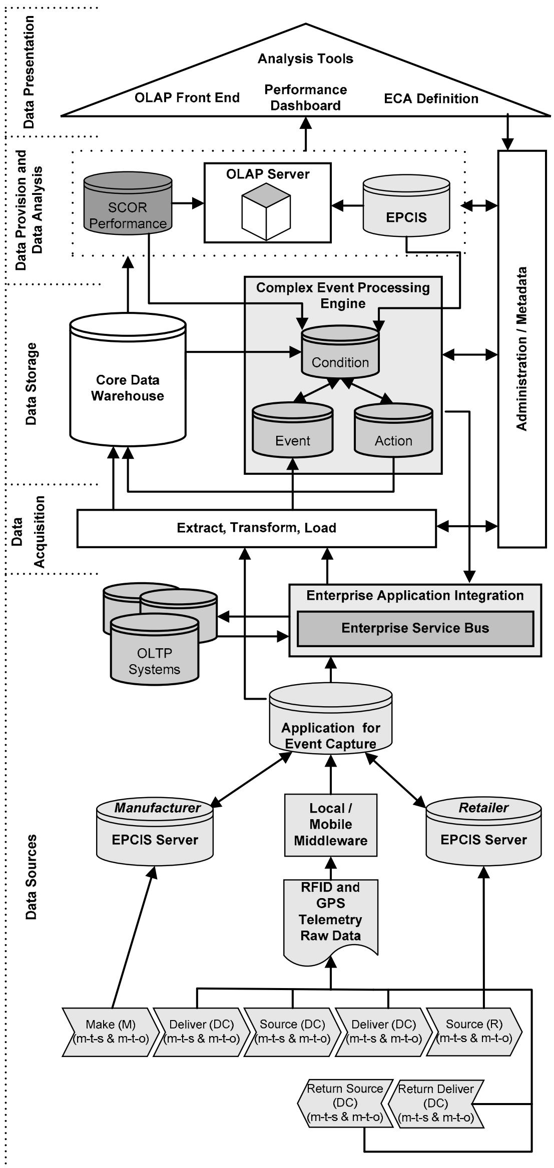


**Fig. 1.** Operational BI Architecture for Supply Chain Management

Code Information Services (EPCIS) event survey and query. The central EPCIS application filters and aggregates data incoming from internal Radio Frequency Identification (RFID) systems as well as from external EPCIS applications and is part of the preprocessing. Conditioned Electronic Product Code (EPC) event objects are transferred to On-Line Transaction Processing (OLTP) systems via Enterprise Application Integration (EAI) platforms. An EAI platform orchestrates incoming basic events by means of an Enterprise Service Bus (ESB). Moreover, it can ensure a high performance data integration from different operational applications.

Extract, Transform, Load (ETL) tools process data directly into the analytical data level. Predefined EPCIS event objects represent time-critical data of operational processes, which will be extracted and loaded continuously. On the one hand the data storage layer contains the Event, Condition, Action (ECA) component, which activates certain actions regarding incoming events dependent on conditions. On the other hand it contains the Core Data Warehouse, which stores subject-oriented, integrated data. Rule-based follow-up actions can be e.g. feedback to operational systems via ESB (closed-loop).

The data provision and data analysis layer sustains data from EPCIS and SCOR data marts, which are relevant for OpBI decisions. Via the On-Line Analytical Processing (OLAP) server data is transformed into problem specific OLAP cubes in order to query performance indicators and EPCIS histories.

The presentation layer provides an analysis and reporting system regarding all management levels by means of a web-based portal. Tactical and strategic management still have access to relevant data marts interactively. Other users, mainly on the operational management level, can use an early warning system via performance dashboards and can access administrative ECA configurations.

### 4.2 Event-Driven Process Components

The following scenarios refer to reference networks concerning a network integrator inside a multilateral product system. There will be no specific SCM planning concepts modeled, but transparency of outbound stocks inside the network integrator's responsibility is assumed.

The following explanations do not consider potentials regarding operational process optimization (e.g. use of mass data extraction, automated inventory, inventory management options, etc.) and they do not consider potentials concerning the deployment of planning algorithms (e.g. use of adaptive, dynamic real-time algorithms). Further explanations focus on an evaluation of operational real-time events regarding analytical aggregated data warehouse data within OLAP queries. The real-time events will be restricted to EPCIS events, which have been generated by an information system. Events from other operational transaction systems are not considered. Analytical data warehouse systems contain SCOR ratios and EPCIS histories in a data mart, as well as control parameters of tactical planning algorithms (e.g. thresholds from the Core Data Warehouse). Every control process which is in responsibility of the network integrator is considered:

| | |
|---|---|
| *S1*: | Source m-t-s-products |
| *S2*: | Source m-t-o-products |
| *D1*: | Deliver m-t-s-products |
| *D2*: | Deliver m-t-o-products |
| *SR1*: | Source Return defective products |
| *DR1*: | Deliver Return defective products |

Decisions based on plan variance (remarkable events) demonstrate a concrete application scenario within a control process. Decision making based on plan variance pursues an increase or a preservation of performance. The assurance of or increase in performance can be regarded as an instrument to ensure quality and can be viewed as an adaptive control instrument within OpBI. In this case, it is important to identify unanticipated events at an early stage. This means, perception latency has to be reduced, so that the manufacturer can already anticipate that his products might arrive at a later point in time. As a result a compensative action can be determined.

Such unexpected events within a reference network may occur during the whole process. This can happen at the manufacturer or at the retailer. Time critical processes proceed in m-t-o scenarios, but also in the distribution of m-t-s products at the network integrator or in out of stock situations. In this scenario every local middleware, which can measure process status and forwards it to the operational EPCIS application, can be an event producer. At this point, preprocessing is already done by relating generated EPCIS object events to business logic. Therefore, events going into the analytical level can be limited to time critical processes. At the analytical level the process status is compared with a target performance value. As a prerequisite the strength of the relations between all relevant information points at the physical process level have to be quantified in a matrix. Those evaluations can be queried as a general pass-through time stored in the SCOR performance database. Therefore, a time critical process object event can be connected to a specific planning milestone. This aggregated view on different time critical EPCIS object events can be used to put focus on delayed processes. Such an event serves as the basis for an application referring to OpBI, because at that time the person in charge has to make a decision in order to avoid errors regarding order execution and performance loss.

Possible results:

- Event A: Delay product exit process of manufacturer XY attached.
- Event B: Delay transportation process from manufacturer XY to DC aggregation number 02 attached.
- Event C: Delay transportation process from DC to retailer ZY aggregation number 02 attached.

An event processing engine could provide a specific rule configuration for every potential relation in case of an occurring delay. This happens via EPCIS histories and SCOR performance at the level of aggregation numbers. A delay could be judged by the relevance of the receiver. If aggregated historic values regarding reliability, reactivity and flexibility fall below the defined planning values including tolerance limits, an adequate action has to be triggered, e.g. the information is send to the responsible manager immediately. Against this background the semi-automatic way of feedback in terms of an open loop to the manager should be preferred [3].

An event-based automation provides a decline of perception latency as well as analysis latency. Lower perception latency can be achieved by automatic identification of process delays. Lower analysis latency may be achieved via automated integration of receiver- and product-context information.

The reaction to plan variations at an early stage can help to achieve scheduled order deliveries, stock deliveries and impeccable orders. Delivery time can be improved by means of aggregated order lead time and further actions. The increase of the performance attributes reliability and reactivity will cause an increase in total costs.

On the basis of potential influences from OpBI supported process control, performance attributes can be controlled referring to cause and effect relations in order to provide a meta-regulation. Expected results have to be checked within defined time intervals using a target/performance comparison according to planned service standards and actual evolution. In case of negative plan variances or high costs, the decision maker is able to check or change analysis rules.

## 5 Appraisal of the Approach

This concept of a system architecture concerning OpBI in the context of distribution networks uses RFID and Event-Driven Architecture (EDA) as core technologies, whereas EPCIS events serve as a basis for process monitoring and SCOR performance indicators may function as rule based control parameters. The system architecture has been described considering the perspective of EDA. Under the terms of Service-oriented Architecture (SOA) as being a loosely coupled architecture all services of OLTP systems, collaborative services (EPCIS queries) as well as analytical services (OLAP queries) can be integrated within overall decision making services. The *high End* of a SOA could be an entire operational decision making service. A synchronic communication of all system components has to be required to achieve this vision [9].

The SCOR concept as a control instrument has been chosen because of its standardized requirements. But it has to be noted that SCOR performance indicators show defects. That means, the value-based shareholder perspective, the social employee perspective, as well as production and marketing point of views are not taken into consideration. Regarding a network integrator long-term competitiveness is important. Referring to this, value-based models already exist, but have not been combined with the SCOR standard [6]. Another objective of SCOR is the integrative evaluation of the entire supply chain. That means, if performance evaluation cross company’s limits, the willingness to participate in information sharing has to be questioned. Concerning the application scenarios, the range of integration has been limited to outbound logistics. Within these scenarios, the network integrator is able to use generated performance data as a control and marketing instrument in order to control performance within the competition of networks and to use performance attributes as a benchmarking instrument of logistic services.

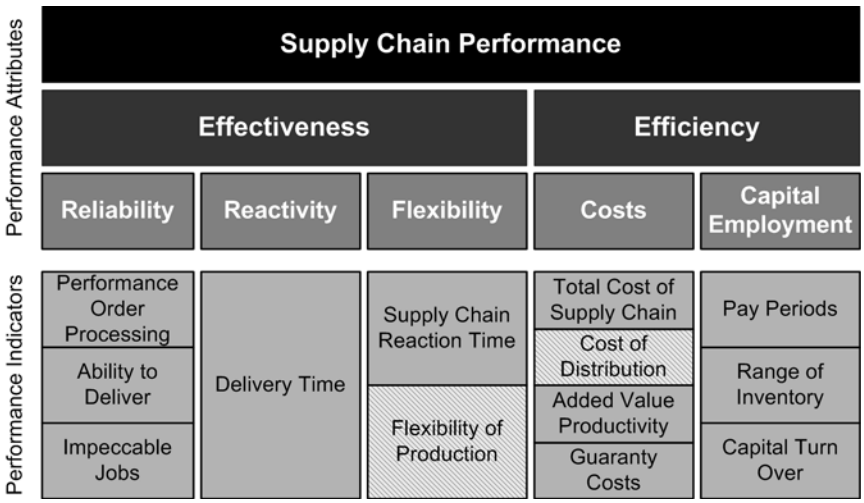


**Fig. 2.** Performance Attributes and Performance Indicators

The paper describes an intersectoral, fast, flexible and adaptive decision support system, which provides the ability of appropriate automated real-time decision making, in order to release the operational management. In doing so, transactional systems have to be enhanced with analytical BI functionalities. Therefore, the basic assumptions and decisions concerning the development of this system are discussed critically.

*Integration of EAI and ETL regarding real-time requirements*
An integration of EAI and ETL promises a technical and functional concentration on minimal real-time information within data and function integration. The data volume that has to be transferred is a determined success factor concerning potential performance restrictions. Looking into the future, further implementations regarding real-time data warehouse research are necessary, in order to generate references to technical system applications depending on real-time data.

*RFID as an auto identification system based on article level and sensor functionality at charging level*
RFID is a requirement for continuous congruency of physical material movement and virtual status information. As basic technology, it determines the potential efficiency of OpBI systems. The system technologies' market penetration is the prerequisite for the usage of OpBI systems, especially regarding article specific labeling.

*EPCglobal as interorganizational communication network*
The integration of the EPCglobal network promises the biggest standardization of RFID-based communication and is the most future orientated communication network regarding a multilateral network integrator. In order to implement more mature applications, further standardization concerning global services and interface definitions is required.

*EDA, ECA mechanisms and optional service orchestration*
Event-Driven Architectures support the flexibility, sensitivity and vitality of systems within an OpBI architecture. Platform independent integration and configuration tools are supposed to be important factors of success regarding future applications. These tools support a simple implementation and prepare an increase in the ability to integrate common OLTP solutions.

*SCOR ratio system as controlling model*
SCOR performance ratios and indicators within a standardized, functional and overall cause and effect model in the supply chain context serve as an implementation of an integrated execution and controlling framework. Looking at the future, adding new perspectives to the model could be an eligible improvement. Through the integration of value-based perspectives, decision problems could not only be evaluated by means of service levels or costs, but also by means of cost-/benefit analysis of decision making artifacts.

## 6 Conclusion

It can be stated, that an OpBI system can offer an effective instrument to support the operational management in a supply chain regarding requirements caused by the increasing complexity in value networks. The scenarios clarified application's flexibility, referring to multidimensional analytical execution and controlling parameters. The causal effects of control potentials have also been shown. Especially independent logistic service providers will use such a control model not only in order to optimize processes but also as a representative benchmarking and marketing instrument in consequence of standardized and transparent performance measurements. Looking at actual technological standardization and market penetration of the required basic technologies, especially RFID, an ad hoc realization of such a concept is not realistic. In fact, this approach reflects a long-term effort in order to optimize processes concerning RFID penetration.

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