Surveying Integration Approaches for Relevance in Cyber Physical Production Systems

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***Abstract*—Flexibility and adaptability are major challenges for modern production systems. To realize them integration approaches are required. Within this paper a literature survey on integration approaches and integration approach types is described based on an attempt towards a detailed characterization of both. It is intended to enable an informed decision for research and development directions towards modern integration strategies as required in Cyber Physical Production Systems.**

***Keywords*—integration, Cyber Physical Production Systems, degree of integration, lifecycle, literature survey**

I. Introduction

To cope with the upcoming trend of producing highly individualized and complex products new challenges came up on manufacturing technologies [1] mostly focusing on the increase of flexibility/adaptability of these systems and their integrated structure as well as processes of use and design.

Using Cyber Physical Systems (CPS) to build Cyber Physical Production Systems (CPPS) could be the foundation to face these challenges. Given that, it can be researched, how manufacturing technologies could be supported by ICTs (information and communication technology), reaching flexibility, adaptability, and integration. Potentials shall be used which come along with an extensive use of technologies from information processing and information exchange like Internet and big data enabling the creation of 'smart' products and smart manufacturing resources - in general, creation and networking of intelligent objects [3], [4], [6].

According to [5], most technologies necessary for the design of CPPS and for intelligent integration of them are already available but may need to be adapted for industrial use. [3] states, that requires a system integration that goes beyond current boundaries of domains and hierarchies as well as across lifecycle phases.

Several research and development activities have considered integration approaches ranging from technology development like UPnP to integration process development like [34]. Several papers have discussed the development of system components easy to integrate in a production system. But up to now there is no general solution; it is even unknown whether this solution will exist or not.

Currently each existing integration approach has its clear target range and boundary conditions which usually depend on the industry of interest. Usually the approaches provide information about how to integrate an element within a given system. In avionic systems there are definitions to integrate air plane components within the available space. In production systems there are approaches for device integration in control systems. Here, only some examples can be named. In any case the focal point is the design of the component to be integrated.

Totally open is the question how to design a system able to integrate elements in the sense of absorbing them also in the long future under currently unknown technological conditions. Here, CPPS can enable new approaches by moving beyond hierarchically structured and "semantically hardwired" systems exploiting service oriented architectures.

To make this possible new ways of system integration are required. As there are several approaches available it is reasonable to analyze existing integration approaches related to their application areas, benefits, and challenges to identify starting points for further research and development. As indicated in [6], there are still potentials for research and development. A literature review and a classification of existing integration approaches and integration approach types may assist the necessary research and development by pointing out general characteristics of integration strategies necessary to consider in future work as well as naming existing approaches as good starting points.

To reach this aim, the paper is structured as follows: Initially the approach of the conducted literature survey is presented. Afterwards, the survey foundation with a general definition of the integration term and a classification for characterizing existing integration approaches and types are given in Sections III and IV. Thereby, the main survey criteria are presented. In Section V integration approaches are reviewed and relevant ones for CPPS are revealed. Section VI concludes with a summary and an outlook on further work.

II. Structure of Approach

The conducted literature survey on integration approaches targets towards the identification of possible starting points for the development of integration approaches fulfilling the re-

978-1-4673-7929-8/15/$31.00 ©2015 IEEE

quirements of creating more flexible and adaptable production systems.

Starting point of the review is the definition of the application field of integration approaches. As all phases of the lifecycle of a technical systems with all its related stakeholders and system parts shall be considered the literature survey is based on a system theory point of view. Thus, basic definitions of the relevant terms of systems and a system oriented definition of the term integration are required. Giving these terms, it is necessary to identify basic criteria for classification of the surveyed integration approaches to enable comparability. Therefore, the term Degree of Integration has been defined covering all relevant characteristics necessary to evaluate the applicability of integration approaches.

Based on these definitions the literature survey was conducted. 35 integration approaches were reviewed and their Degree of Integration was derived. Furthermore, existing integration approaches were assigned to integration approach types named in literature. Given the page limitation of this paper, it has been tried to reveal typical properties for those integration approach types as well as to conclude properties integration approaches have to provide to be used in typical lifecycles relevant in technical system design and use. Exploiting the literature survey results relevant approaches for further consideration have been proposed.

III. Defining a General Integration Term

To give a good starting point a general definition of the integration term shall be provided. Since integration principles are applicable to almost any domain there is a great diversity of definitions of this term in literature. Common to all definitions is that there are at least two atomic (non divisible from an outside point of view) entities which interrelate.

Lehmann [13] states that the phenomenon of integration may be interpreted best in terminology of system theory. Accordingly, integration is a specific kind of conjunction of elements to the whole of a system.

Following a system oriented view of integration, system related terms have to be given before defining the term integration itself.

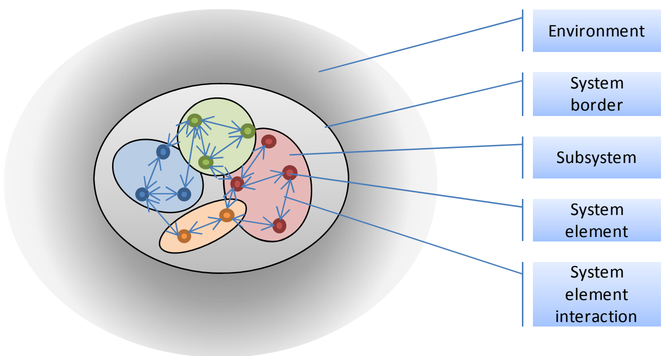

Fig. 1. Visualization of the System Definition and the General System Hierachy

Based on [7], [8], [9], [10], and [11] the following terms are defined:

A *System* is an entirety of elements which interact in a way enabling the entirety to fulfill a defined aim. A system has a system border delimiting the entirety of system elements and its interaction from the rest of the environment (see Fig. 1). The system aim may be more than the simple addition of the capabilities/behavior of the elements of the system. A *Systems' Aim* differs from those immanent to the system like its tendency to self stabilization. It defines the fulfillment of a purpose an artificial system is set up or utilized for.

A *System Element* is an identifiable part of a system providing essential parts of the overall system behavior by its own and enabling the system to fulfill its aim. A *Subsystem* is a system itself. Besides it is part of and fully contained by another upper system. In the scope of the upper system the subsystem is similar to a system element.

The *System Border* is the borderline between system elements with their interaction and objects not considered as system elements but possibly interacting with system elements.

Interaction of system elements is the process of mutual influencing internal element behavior using element interfaces.

Fischer [12] defines integration as the unification of something differentiated as well as the completion of those to a greater whole. The integration is seen as the process itself as well as the outcome of the integration process depending on domains or authors. Furthermore, he states that integration intentionally tries to create systems with emergence. Considering all definitions, the authors frame the term as follows:

Integration is the creation of interaction between system elements on which the system or its parts depend on. The objective of integration is the implementation of functions realizing higher capabilities, than those of its parts. These capabilities are required to fulfill the system aims.

A systems*' Function* is considered as an entirety of interactions of system elements exposed to the environment by a single element of the systems' interface. It may have various characteristics ranging from mathematical function over physical and logical dependencies to common behavior.

Systems, system elements, and interactions between system elements can have various natures. To make these differences identifiable the term of Degree of Integration can be used as a characterization of integration approaches.

IV. Defining the Degree of Integration

As mentioned, Integration is a complex term. It is necessary to find a kind of characterization to cope with it. In literature the Degree of Integration is common. Fischer [12] defines this term as a detailed description of integration and outlines the diversity of it. Basically, the Degree of Integration provides information about which and how a system element is integrated, i.e. it reflects both the characterization of the interactions of system elements to be established as well as the characterization of the process of establishing the interactions between system elements.

Based on [12], the authors propose a refinement of the Degree of Integration to enforce comparability of integration approaches. It shall be characterized by six criteria: Integration Object, Integration Direction, Integration Range, Degree of Automation, Point in Time of Integration, Integration Manner.

The *Integration Object* can be considered as a system element which is integrated in a system with its interactions among other system elements. Integration Objects are dependent on the domain and vary consequently [12], [14]. A classification by domains is given by Fischer [12]. He gives an overview of possible Integration Objects from different domains, e.g. divisions and companies (domain: Business economics), data and software (domain: Computer science). An example of an Integration Object could be a company within a corporate group that may be integrated by contracts on capacities within a tuned supply chain. Another example can be an electrical engine which is integrated mechanically, electrically, and control related in an electrical car.

Integration Object Interaction represents the type of interaction interface of a system element to be integrated. In principle, a characterization can be made by: energy, material, signal/information [15], [16]. But in some literature it can be found that these three interaction types are extended by additional interactions [17], [18]. [18] states, that the meaningful number of different values to distinct interface types depends on the context. An example of Integration Object Interaction related to the company within a corporate group could be the order exchange and/or the transfer of goods/knowledge/capacities from one company to another. Another example can be the mechanical mounting of the electrical engine in the car and the exchange of electrical energy with the engine.

The *Integration Direction* describes whether the integration takes place along or across the different levels of a system (cf. [12]). It can be classified in horizontal, vertical, and diagonal integration. Here the direction is seen as interaction between or along the layers of the element hierarchy f the considered system. In some cases a clear separation between horizontal and vertical integration is not possible. Thus, the existence of a hybrid form is necessary: Diagonal integration describes the simultaneous presence of horizontal and vertical integration [19], [12]. An example of Integration Direction related to the considered company within a corporate group could be a kind of relation across or along the group subsidiaries hierarchy which is usually both horizontal (with respect to partner companies) and vertical (with respect to the holding). Another example is the integration of electrical elements in the electrical car which is a horizontal integration.

Integration Range is based on the consideration of the interactions between different system elements and their impact on the capability of a system element to be integrated in the overall subsystem function to fulfill the system aim. So, it specifies the degree of interaction of the system elements within one system. An example of Integration Range related to the considered company within a corporate group could be the kind, strength, and density of relation between subsidiaries within the group.

Generally the Integration Range can be considered as trivial, complicated, or complex. But this distinction is too simple for a detailed characterization of integration approaches. More specific, the Integration Range can be considered from different points of view like the capability view [20], the complexity view, and the technological view [16]. The Integration Range is further classified into: Functional Integration Range, Complexity Range, and Element Identification Range.

The capability view of the Integration Range – The *Functional Integration Range* - covers a function oriented consideration, i.e. it defines, to which degree a system element is able to participate in the system function to fulfill the system aims. It can have three values coexistence, compatibility, and interoperability which are based on each other [20].

The complexity view of the Integration Range – the *Complexity Range* - covers a structure oriented consideration, i.e. it defines, to which degree system elements interact within a subsystem with each other. As this degree is a continuous value only the two extremes simple integration and complex integration will be distinguished here.

The technology view of the Integration Range - the *Element Identification Range* - covers the degree of identification of system elements with each other within the integration process. Thereby it specifies to which extent the integrated system elements can be identified as individual system elements after the integration process. It can have three values: Component Integration, Modular Integration, and Physical Integration [16].

The example of Integration Range related to the considered company within a corporate group could be extended to the required interoperability of the companies involved in the group, resulting in a complex integration based on complex contract, material and financial flows or modular integration, preserving the identity of the involved companies. In contrast the Integration Range of the engine in the electrical car can be seen as simple integration looking on the electrical connections requiring compatibility for component integration.

Degree of Automation is based on the consideration of the level of autonomy and self-reliance a system element can have within the process of establishing the necessary interactions with the other system elements [21]. It is characterized by a pair of values. The first part of this pair can be one of the values Manual Integration, Semi-Automatic Integration, or Automatic Integration representing the level of necessary human intervention in the integration process. The second part of the pair can have the values Reactive integration or Proactive integration representing the origin of the activation of the integration process. An example of the Degree of Automation related to the considered company within a corporate group could be the manual and reactive integration of a new product within the SAP system. Another example is the manual and proactive integration of the engine in the electrical car.

Point in Time of Integration is based on the consideration of the system lifecycle. It reflects the lifecycle phase the system element integration is taking place. It can have four values: Engineering Time Integration, Installation Time Integration, Use Time Integration, or Deconstruction Time Integration covering the main life cycle phases. Related to the considered company within a corporate group the Point in Time of Integration could be defined by the need to establish necessary contracts for delivery of parts of final products during the engineering of the product. Thus, we are in preproduction phases, i.e. Engineering Time Integration. The electrical engine in an electrical car shall be considered at engineering time and at installation time.

Integration Manner (System Coupling) describes how the system elements are integrated [12]. According to cf. [22], [12], and [23], the Integration Manner is classified in: Non-Coupled Systems, De-Coupled System, or Coupled System which can be divided in Merged System, Tightly Coupled System, Loosely Coupled System. An example related to the considered company within a corporate group could be a type of relation between subsidiaries. They may coexist without influencing each other; have contracts of cooperation or contracts to avoid rivalry. Thus they are loosely coupled system. The electrical car, in contrast, will establish a tightly coupled system.

V. Analyzing the Results from the Literature Survey

Within the literature two types of publications can be found: publications about integration approaches and publications about types of integration approaches. Publications about integration approaches usually consider one special technology, process, or architecture the integration is related to while the publications about types of integration approaches usually consider more general aspects usually covered by more than one integration approach.

In a literature survey the authors have collected 35 established integration approaches (see TABLE I.) In addition, they have collected 15 integration approach types which are referenced in publications and additionally described in literature separately as integration approach type. This collection reflects a broad range of publications relevant in the field of integration, but it is far from being a representative sample. After characterizing integration approaches according to the Degree of Integration and mapping those to integration approach types (see [2]) it was possible to elicit integration approach type properties, typical properties regarding different lifecycles, and integration approaches which might be worth considering in context of CPPS.

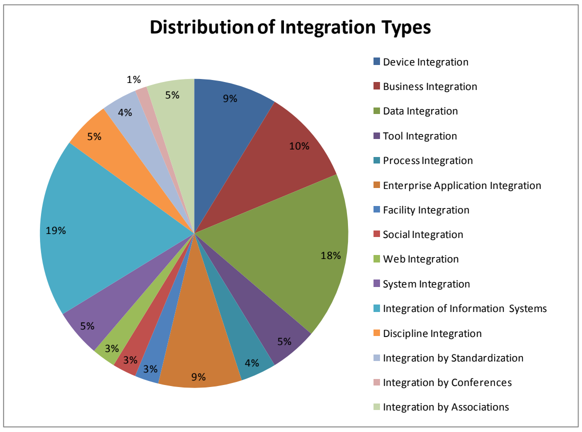

Fig. 2. Distribution of Integration Types among all Integration Approaches

The mapping of integration approaches to integration approach types results in a well distributed sample, see Fig. 2. According to literature [1], [3], [5], [6] all integration approach types identified in [2] are relevant for CPPS.

TABLE I. List of Considered Integration Approaches

Integration Approach	Source/Publication
TPS (Toyota Production System)	[39], [40], [41], [42], [43]
IWS (Integrated Work System)	[44], [45], [46], [47], [48]
PROFINET – Open Industrial Ethernet Standard	[49], [50], [51]
AS-Interface	[52], [53], [54]
Service Oriented Architecture	[55], [56], [57]
Business to Business Integration	[58]
Recruiting Strategy (Social Networks)	[59], [60], [61]
BIZYCLE	[33], [62], [63]
Schema Matching (LSD, COMA)	[64], [65], [66], [67], [68]
SYSMOD	[69], [70], [71], [72]
Rational Unified Process	[73], [74], [75]
UDDI - Universal Description Discovery and Integration	[76], [77], [78], [79]
WSDL - Web Services Description Language	[80], [81]
ETL – Extract, Transfer, Load	[82], [83], [84], [85]
INCOSE (International Council on Systems Engineering)	[86], [87]
VDI 2206 - Design Methodology for Mechatronic Systems	[16]
IEC 61131-3 – Programmable Controllers – Programming Langu.	[88]
AutomationML	[89], [90]
IEC 61850 - Communication Networks and Systems in Substations	[91], [92], [93], [94]
E2E Bridge	[35]
Enterprise Application Integration	[36], [37]
OLE - Object Linking and Embedding	[96], [96]
OLAP -On-Line Analytical Processing	[97], [98]
Agent Oriented Systems	[21], [99], [100], [101], [102]
Holonic Manufacturing Systems	[26], [27], [28], [29]
ISO-OSI 7-Layer Model	[103], [104]
Middleware	[105], [106], [107]
FDI	[108], [109], [110], [111]
ISA 95	[34], [112], [113], [114]
Open Engineering Service Bus	[31], [115]
RPC	[116], [117], [118], [119]
eCl@ss	[32], [120], [121], [122]
OPC	[123]
Standardization	[124], [125], [126]
“Industrie 4.0”	[1], [6], [127], [128], [129], [130]

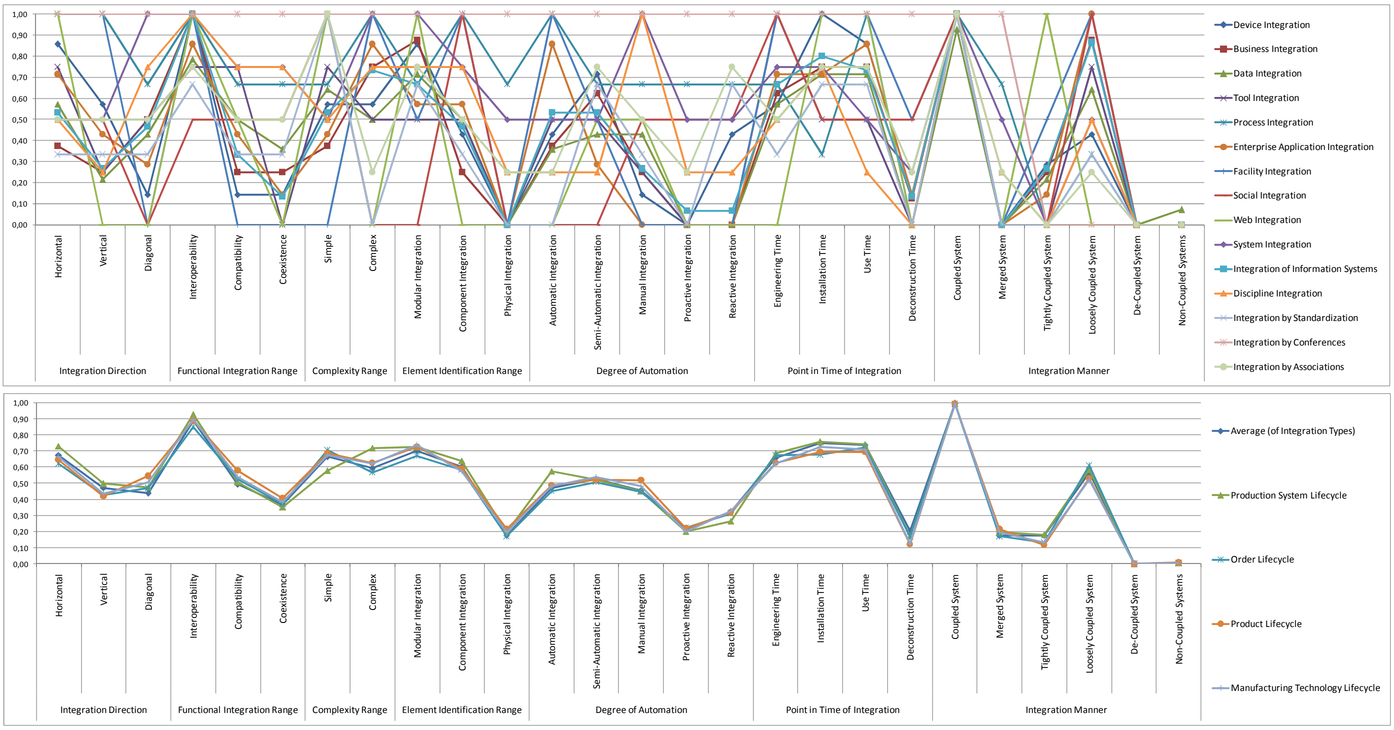

Fig. 3. Upper Figure: Integration Type Characterization; Lower Figure: Characterization of the Different Lifecycles

A. Analyzing Integration Approach Types

For the sake of readability only the integration approach types are visualized in this paper. For more details see [2]. Looking at the upper part of Fig. 3 it shows, that the different integration approach types have (at average) very different characteristics. The scaling between 0 and 1 for all values indicates the relevance of the related value of the Degree of Integration for the named integration approach type. 0 means no and 1 indicates 100 % relevance. The two examples Data and Discipline Integration are considered here to support reading the figure.

Data Integration considers the process that compounds data from different sources and it provides users a unified view of this data. Data Integration is characterized by a loosely coupled, horizontal integration of information providing systems (mostly software systems). Those systems need to be integrated during installation and use time. The systems of interest are integrated following modular integration providing interoperability. Integration of data is simple and done semi-automatically, partially controlled by human, or manually.

In contrast, Discipline Integration considers continuity of the engineering disciplines to improve integration of the different activities one discipline is involved in and to improve continuity of the disciplines across all phases of the lifecycle of an engineered system. It is mainly considered at engineering and installation time providing loosely coupled systems which are diagonal integrated within a modular or component integration. The disciplines work interoperable. The integration is complex and done manual in most cases.

The made analysis shows that the analyzed integration approach types have completely different foci resulting in systems integrated in different ways. It is likely impossible to find a common integration approach type. Nevertheless, it can be seen that some characteristics like diagonal integration, physically integrated, and tightly coupled are rarely addressed among the 35 considered integration approaches which either can be seen as open research issue or irrelevant in practice.

B. Analyzing Lifecycles

Within the consideration range of technical systems there are different technical and economical relevant objects to be considered and distinguished. Each of them will have its own characteristic lifecycle with specific properties related to the nature of the object. Most relevant lifecycles are those of Product, Production System, Manufacturing Technology, and customer Order (following [24]).

The lifecycle of a *Product* is dedicated to the product business, the lifecycle of a *Manufacturing Technology* application system to the component business, and the lifecycle of a *Production System* to the solution business named in [25]. The lifecycle of an *Order* is related to the interaction of a product provider with the customer to ensure creation of the product needed by the customer.

The lower part of Fig. 3 depicts the characterization of the Degree of Integration according to the use of the integration approach types within the four different lifecycles. While there is no pattern (favored characteristics) found among the different integration approach types (upper figure), surprisingly, the lower figure shows a preference in properties through all lifecycles which is also equivalent with the average characterization of all integration approach types. So, it might be reasonable to consider the suitability of integration strategies of one lifecycle for another one which could have to deal with same challenges in research activities.

Integration approaches which occur in all of the four considered lifecycles are: Holonic Manufacturing System [26], [27], [28], and [29], Enterprise Application Integration [36], [37] Rational Unified Process [30], Open Engineering ServiceBus [31], and eCl@ss [32]. Besides them, Order lifecycle specific integration approaches are: ISA 95 [34], BIZYCLE [33], and E2E Bridge [35]. ISO/OSI 7 Layer Model is relevant in Production System and Manufacturing Technology lifecycle. Those are the candidates which could be worth looking at it within the development of integration strategies for CPPS and future manufacturing systems.

VI. CONCLUSION

Within the described approach a set of 35 well established integration approaches have been surveyed and classified. In parallel, 15 integration approach types described in literature have been investigated. Although there is a great diversity within the investigated integration approaches and integration approach types there are some interesting findings.

The first finding is related to the applicability of a detailed characterization of integration approaches and integration approach types based on the Degree of Integration. This characterization using the six main criteria Integration Object, Integration Direction, Integration Range, Degree of Automation, Point in Time of Integration, and Integration Manner is possible and can lead to a better understanding of integration strategies.

As a second finding, when assigning integration approach types to the different lifecycles the criteria of the Degree of Integration have mostly the same values than the integration approach type average (see Fig. 3). So, it might be reasonable to look at integration strategies in other lifecycles which might have to deal with same challenges to gain ideas and starting points for the development of own integration strategies.

As a third finding: Most relevant integration approach types consider horizontal, modular or component, automatic or semi-automatic integration at engineering, installation and use time, aiming at interoperability of system elements which are loosely coupled.

The fourth finding opens up new research directions. The developed Degree of Integration might be also usable as mean for requirement description in cases where a new integration strategy has to be developed. Starting with a characterization based on a system oriented view of the system elements to be integrated existing integration approaches and types can be reviewed for applicability as well as new dedicated approaches might be developed. The validation of the applicability of this method is outstanding as well as how the Degree of Integration could be used to evaluate the production system and its element receptiveness.

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