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# Designing of Smart Logistics Modules as Cyber-physical systems for Load carriers

## Entwicklung von Smarten Logistikmodulen als cyber-physische Systeme für Ladungsträger

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**The growing demand for individualized vehicles and alternative power units are challenging the automotive industry. In order to cope with these challenges and realizing the simultaneous production of different variations and models within the same factory, innovative production systems like the Matrix-structured Manufacturing System or Fluid Manufacturing System have received increasing attention. However, the realization of alternative production systems imply the development and the use of cyber-physical systems (CPS). Hence, by networking production modules, autonomous guided vehicles, smart load carriers and utilizing process relevant information, the aim of a flexible and versatile production can be achieved. This paper describes the development process of Smart Logistics Modules as CPS for Smart Load carriers.**

*[Keywords: Production logistics, Cyber-physical systems, Smart Load Carrier, Asset-Administration-Shell]*

**Die steigende Nachfragen nach individualisierten Fahrzeugen und alternativen Antriebskonzepten stellen die Automobilindustrie vor neue Herausforderungen. Um diese Herausforderungen zu bewältigen und die simultane Produktion verschiedener Varianten und Modelle innerhalb derselben Fabrik zu ermöglichen, haben innovative Produktionssysteme wie beispielsweise die Matrixproduktion und die Fluide Produktion jüngst zunehmend Aufmerksamkeit erhalten. Jedoch ist für die Realisierung dieser alternativen Produktionssysteme, der Einsatz von CPS erforderlich. Durch die Vernetzung verschiedener Produktionsmodule, Fahrerloser Transportsysteme, Smarte Ladungsträger und der Auslastung relevanter Prozessinformationen kann das Ziel einer flexiblen und wandlungsfähigen Produktion erreicht werden. Die vorliegende Veröffentlichung beschreibt die Entwicklung von Smarten Logistikmodulen als CPS für Smarte Ladungsträger.**

*[Schlüsselwörter: Produktionslogistik, Cyber-physische Systeme, Smarte Ladungsträger, Verwaltungsschale]*

## 1 INTRODUCTION

The continues trend towards individualized products, shorter product life cycles and rapid technological innovations drive manufacturers to reconsider their strategies [RSJ+19, GSB17, Pop18]. These development also lead to focus on alternative production systems like the Matrix-Structured Manufacturing System (MMS) or Fluid Manufacturing System (FLMS) [HBK+19, BFD20, FD20]. The named production systems are characterized by CPS, which enable the regarding flexibility and versatility [AFF+20]. For example, the concept of FLMS originates from the vision that cyber-physical systems can be combined to form new resources as needed [FAF+20, AFF21]. CPS allow besides the physical action and the data exchange between different resources, the reconfiguration of production and logistics systems [FAF+20].

However, to exploit the full potential of a logistics system in a FLMS, CPS e.g. autonomous guided vehicles (AGV), Smart Shuttles and Smart Load carriers are necessary.

Smart Load carriers can be described as Load carriers, which are equipped with different sensors and computing devices to provide Smart Services e.g. tracking & tracing or condition monitoring. Smart Services are novel services to provide additional value to customers [SP17]. Smart Load carriers have been used for different applications. For example, the seamless tracking and tracing across companies and for Condition Monitoring so far [Joh19, KSG21]. They contributed to cost optimization and increase the traceability [KSG21].

This contribution outlines the development of Smart Logistics Modules for Smart Load carriers. The following section provides an overview of the state of the art. Section 3 describes the methodology of designing CPS. In Section 4, the Smart Logistics Modules are presented, which are followed by use cases in section 5. It concludes with a conclusion and outlook in Section 6.


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## 2 STATE OF THE ART

### 2.1 CYBER PHYSICAL SYSTEMS

CPS play an essential role in the I4.0 strategy of the german government to safeguarding the long-term competitiveness of the manufacturing industry [MBV18, Kag13]. By the integration of CPS in manufacturing and logistics interconnected industrial value creation can be realized [LDL+17, MBV18, LFK+14].

CPS are described as linking physical with the virtual world [LBK15, HS19, VBH17]. Further, they initiate actions and can mutually control each other and enable the information exchange via the internet, which is also known as "Industrial Internet of Things (IIoT)". CPS are already being used in many areas, such as in engineering, manufacturing and in logistics [MBV18, Kag13].

In CPS, the relevant data are generated by sensors and actuators and is used to utilize Big Data applications and generate benefits for manufacturers [LBK15]. Recently, it is also used to create virtual image of an asset, which is termed as a "Digital Twin" [BMK+19].

### 2.2 SMART LOAD CARRIERS

A load carrier is a load-bearing means for combining goods into a load unit [DIN89]. Further, Load carriers are in different forms e.g. bins, containers, pallets or as special load carriers available [HSD18, Klu10]. They are used to secure a load e.g. material, parts or products. Since the development of affordable sensors and different telecommunication technologies, load carriers are increasingly equipped with these technologies as a Smart Load carrier [LBK15].

The applied technologies add different benefits compared to a conventional load carrier [KSG21]. To illustrate the advantages and the use of Smart Load carriers, several relevant examples will be presented next.

The first approach is realized by the implementation of a Global Positioning System (GPS). The GPS is a satellite positioning system, which is used to localize any object with an accuracy of several meters [SBT+08]. Moreover, it is an active system, but since recent developments, a passive signal transmission is also possible [KKB+14]. Further, the main benefits of a Smart Load Carrier with a GPS module is that, there is no additional infrastructure necessary [SBT+08].

The next approach is the use of Radio Frequency Identification (RFID) tags. In the RAN (RFID based automotive network) project, Volkswagen used tags for increasing the transparency by an automated event based tracking [Fra06, Lep14]. The passive RFID tags were recorded with new information after passing the gates. This function was used for tracking & tracking and monitoring of load carriers. Besides the automotive industry, RFID has been applied in different sectors for e.g. in food logistics and transport logistics. The data generation and collection is thereby performed by integrated sensors in the load carriers. The approach can be extended with a WLAN interface, which enables further applications. For example an interface to an Enterprise Resource Planning system [Fra06].

In the next approach, a smart object is created via Universal Mobile Telecommunications System (UMTS). The collected sensor data are transmitted as a package via UMTS to the backend [ZF20]. In the project DyCoNet, different container are equipped with UMTS modules for a dynamic, autonomous and energy self-sufficient container network in the airfreight industry [Hil13].

Another solution is the connection via low-power wide-area network module (LPWAN) for interval-based communication and transmission of data. In the project iSLT.NET in a special load carriers, a LPWAN module is combined with a GPS module. The GPS module is used for the tracking and the LPWAN module is used to transfer the generated and collected data to the backend [Joh19].

The last approach is the Narrowband-IOT (NB-IOT). NB-IOT is based on the LPWAN technology and is used to connect smart sensors e.g. ambient lights, temperature or humidity sensors [FAT18, WXV+20]. The Fraunhofer IML and the European Pallet Association (EPAL) developed a NB-IOT low-cost smart tracker for pallets [JB18, FHK+20]. The tracker uses the german telekom NB-IOT and works with a mobile battery solution. The main advantage of the narrowband is the good building and large coverage. The trackers can even be tracked through walls or in underground [JB18].

Most applications and projects involving load carriers are focused on the data creation and applications like tracking and tracing. However, they can be used for further applications, like an event-based decentralized material flow control.

## 3 METHODOLOGY

The Reference Architecture Model Industry 4.0 (RAMI4.0) describes a three-dimensional coordinate system or cube, which allows to decompose complex interrelations into smaller, more manageable problems (Figure 1). RAMI4.0 is divided into three dimensions: the product life cycle (Life Cycle & Value Stream), the hierarchy of the automation pyramid (Hierarchy Levels) and the architecture layers (Layers) [Fed18]. The product life cycle represents the product view (horizontal integration), the hierarchy levels represent the production view (vertical integration) and the architecture layers represent the mapping of real resources into the digital world.


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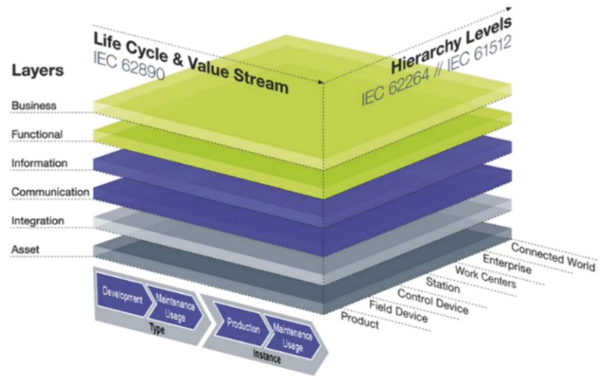


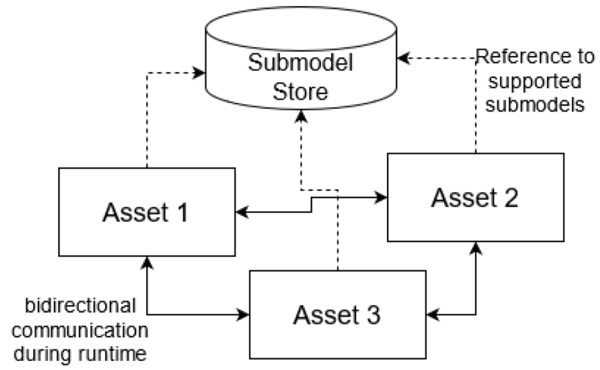


In order to integrate a physical asset into the architecture, it is equipped with an asset administration shell (AAS). The combination of asset and AAS forms the I4.0 component. As a digital image of the asset, the AAS provides the interface for the communication layer used in the RAMI architecture. The administration shell contains a self-description of the physical component with the associated functions and properties. This allows virtualization of the operating states and control of the I4.0 component. A complete operating resource or a sub-component can be regarded as an asset.

Nestability of I4.0 components is a key feature of the administration shell concept. The granularity required for this must be defined as needed depending on the use case and operating resources. I4.0 components enable the synthesis of overarching process modules from individual I4.0 subcomponents, which in turn can appear externally as an integrated production plant. The implementation of the administration shell allows an exchange of operating, states and the provision of functions across several I4.0 components involved in the production process. This makes it possible to ensure data operability and transparency across all operating equipment and process steps involved in production.

## 3.1 Asset Administration Shell

For I4.0 components to be able to communicate with each other, they need a common language and a common understanding of what they are communicating about. This shared understanding, the mutually usable vocabulary, is mapped in the current concept by so-called submodels, which are used to describe properties and capabilities. A submodel describes exactly one technical aspect. To ensure that the common understanding, the semantics, is as clear as possible and is shared and used by as many I4.0 components as possible. Submodels are published at a central location and made accessible to all communication partners.

An I4.0 component intending to allow other communication partners to use it advertises itself to them and refers to one or more submodels it supports (Figure 2). In doing so, it describes its own capabilities and properties as an aggregation of all submodels used. Other communication partners are then able to communicate directly with the I4.0 component or access the properties and capabilities declared in this way [EJT+21].

### Submodels

A submodel specifies exactly one domain-oriented aspect of an I4.0 component. To this end, it specifies the properties associated with the attribute, the events that occur, and the operations provided. The individual elements are explained in the following.

### Properties

A submodel can specify any number of properties. A property describes a static or variable attribute, e.g. a position, color or serial number. If an I4.0 component communicates a property, the specification is assumed to be valid until the component sends an update. Each property has a unique name and a data type within its submodel. The data types are based on the JavaScript Object Notation (JSON) schema [EJT+21], non-primitive data types can optionally be further specified by the user.

### Events

Unlike properties, events have a unique time reference. Therefore, the event contains a timestamp. Examples for events are the arrival of an AGV at its destination, the completion of an assembly process or similar. Events also have a unique name and can communicate other data fields. Each data field is specified in the same way as a property.

### Operations

While properties and events describe outgoing communication, operations specify services that can be called by other components. For example, a manufacturing process


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can be initiated. Operations are identified by their unique name within the submodel. Optionally, parameters can be specified. Unlike events, a return value can also be specified, e.g. to report whether the operation was successful.

### 3.2 Technical Implementation of the AAS

The submodels described so far only define the content via an I4.0 component's ability to communicate with each other, but not how the actual communication is technically implemented. In the present concept, Message Queuing Telemetry Transport (MQTT) [BG15] is used for this purpose, and the content is serialized with JSON [Pal20]. MQTT was chosen due to its high prevalence, effectiveness, and simplicity. In principle, however, mapping to other communication protocols is also possible. The present submodel concept is mapped to MQTT topics as follows:

```
<Namespace>/
<I4.0-Component>/
<Submodel>/
<Submodelelement>
```

In this case:

- **Namespace** describes a unique identifier for grouping components, e.g. by application, organizational affiliation etc.
- **I4.0-Component** is the name of the component and unique within the namespace.
- **Submodel** is the name of the respective submodel implemented by the I4.0 component, as defined in the associated submodel specification.
- **Submodelelement** is the name of the respective property, event, or operation. For operations, the sub-topics "Request (REQ)" and "Responsible (RESP)" are additionally introduced to be able to distinguish between the call and response of the operation.

## 4 Smart Logistic Modules

In the design process of the Smart Load Carrier, various Smart Logistics Modules were developed and implemented with an AAS. In the following sections, the implementation process will be described in detail.

### Processing Module

As a processing module, a Raspberry Pi 4 was selected. The Raspberry Pi will be enable with its different interfaces General Purpose Input/Output (GPIO) with 3.3 V output and Universal Serial Bus (USB), the necessary performance to connect the different Smart Logistics Modules [Wat16]. For the energy supply of the Raspberry Pi and the Smart Logistics modules a portable power bank is used.

### Condition Monitoring Module

The first Smart Module is a condition monitoring based on a BME280 sensor, which includes a potentiometer, temperature and humidity sensor for monitoring. In the back-end, the program for the sensors are running on a python script. Afterwards, the sensor data are collected and published via JSON file with the different topics to the MQTT broker. In the front-end, the developed smart services can be started on a user-interface, the AAS dashboard at the research campus Active Research Environment for the Next generation of Automobiles (ARENA2036).

### Load Carrier Management

The second module is for load Carrier Management. In order to detect the filling level of the load carrier, two time-of-flight sensors were implemented. The two time-of-flight sensor measures the echo propagation time of an emitted light signal to the object surface and back [Hag08]. In this context, the two sensors are measuring the distance to the content in the load carrier. If it falls below a defined value, it will change the state of the systems from “full” to “empty”. The relevant data is output via the application programming interface (API). In the next step, the state of the load carrier is published to the MQTT broker. Further, the service can also be started on the front-end via dashboard. The Smart Logistics Module can also be reconfigurated to different size of load carriers.

### Tracking and Tracing Module

The third module is a Tracking and Tracing Module. Therefore, an ultra-wide-band Tag (UWB) Tag is used. UWB is a localization technology with accuracy up to 10 cm, even under difficult condition e.g. through walls [Sch15, Hil12] The sensor is measuring the exact location with the coordinates (x, y, z) within the ARENA2036. The coordinates are output via the API and published to the MQTT broker.

### Master-data

Besides the submodules, the AAS can also contain the process relevant master data. In the context of the ARENA2036, the Smart Load Carriers is supplying the worker with the Computer-Aided Design (CAD) model and the list of the parts in the load carrier. The necessary data is provided via a cloud server and the access will be provided as a submodule on the MQTT Server.

### Visualization and sensor data fusion

In order to develop new Services, the different sensor data are fused and visualized with different visualization tools


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(Grafana and Peakboard Designer). If the material is damaged during the transportation or the production process, the exact location of the Smart Load Carrier as well as the exact time of the damage can be determined.

The following Figure 3, shows the architecture of the implementation.

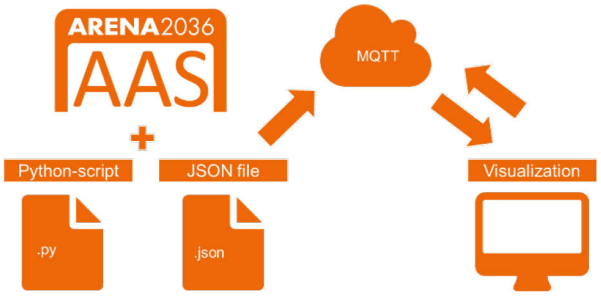


*Figure 3. Architecture of the implementation*

## 5 USE CASES

In the context of the research campus ARENA2036 two different use cases were developed and tested. The aim of the uses cases are to demonstrate an event-based decentralized material flow-control. Decentralized material flow control can be described as the capability of system elements to interact with each other and making autonomous decisions [HNS20, HW10].

In the first use case, the sequence starts from the load Carrier Management Module. If the material is removed from the load carrier, the Load Carrier Management Module publishes a topic with the new state “empty” to the MQTT broker. Further, it will also publish, the location of the load carrier. In the next step, the empty load carrier triggers the operation “move to id”. Afterwards, if an AGV is available, an order will be generated in the AGV master control and the load carrier will be transported away.

In Figure 4 the sequence chart for the process is illustrated.

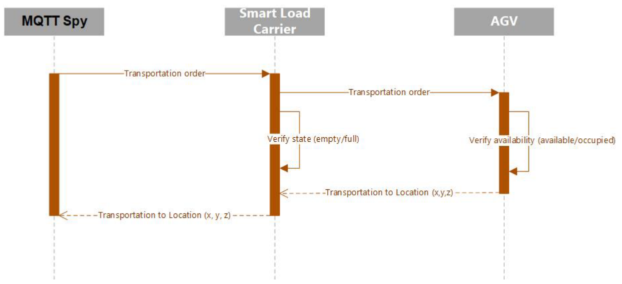


*Figure 4. Sequence of use case 1*

In the second use case, the transportation process will be triggered via the Condition Monitoring Module. If the sensor data exceeds a certain value for example a defined temperature, an event will be published to MQTT broker. Thereafter, the operation transportation process will be started. As in the previous use case described, if an AGV is available, a transportation order will be generated in the AGV master control and the load carrier with the defect material will be transported away.

The load carrier with the defect material will be picked up at the exact location “offset (x, y, z)” and the replacement material will be ordered simultaneously. Figure 5 shows the sequence chart for the process of this use case.

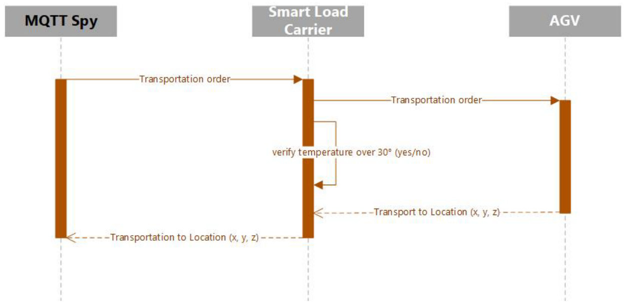


*Figure 5. Sequence of use case 2*

We modeled the coordination of the process via Node-RED. Node-RED is a browser-based, graphical, open source and low code programming environment. The process can be modeled in the form of so-called "flows" and afterwards processed in a server-side engine. A node is a data processing step. It is always triggered when a new data is present at the input [Bar18, Hag21].

Node-RED is designed to be extended with its own node types to perform user or application specific tasks. An extension based on the AAS ensures that for each submodel currently found in the network, a node type is created for its properties, operations and events, if available. Thus, it is possible to model flows in Node-RED that can access all these elements of all management shells and thus of all assets. [Hag21]. In Figure 6 the flow of the first use case with the necessary operations and events is presented.

## 6 CONCLUSION AND OUTLOOK

In this paper, use cases with different decision mechanism were presented. The described use cases are developed and tested at the research campus ARENA2036. The uses cases show, that a decentralized material flow control is possible. However, through the increasing amount of CPS and production conditions, the material flow control will be more complex in a FLMS. Therefore, additional decision-making mechanisms will be necessary to exploit the full potential of the decentralized material flow control, as shown in previous studies [BHS20].


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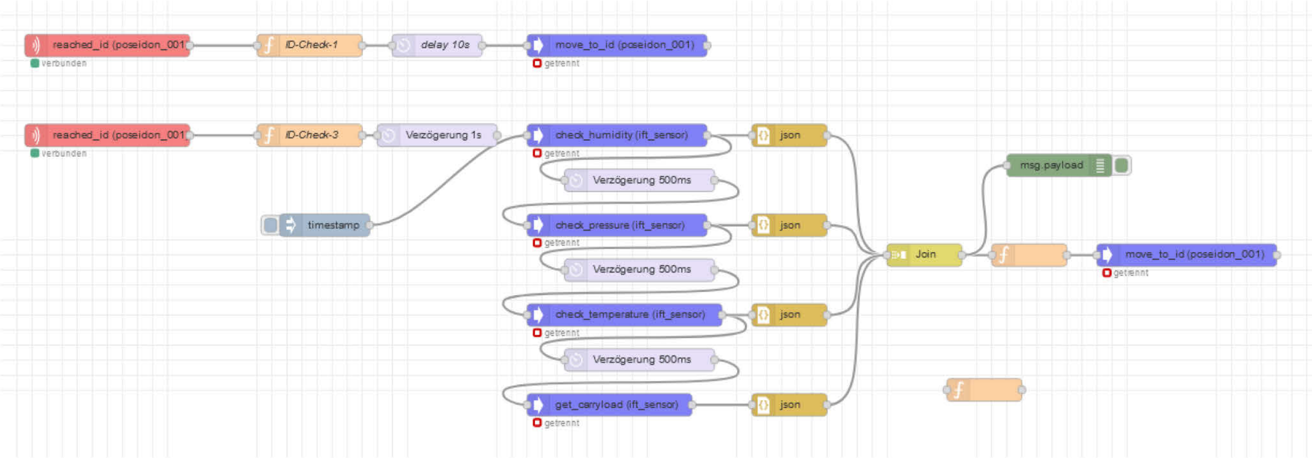


*Figure 6. Process flow modulation in Node-RED*

Further, the presented lightweight implemented is suitable for a pilot project and a limited number of decision mechanism. However, for a more complex implementation a decentralized master controller e.g. OPC-UA client with publish and subscribe patterns with various decision mechanism in production and logistics is necessary. The decentralized master controller will be able to control the logistics and production process with a high number of different decisions mechanism. Moreover, it will help to decide between the various different decision-making mechanisms.

Further, the Smart Load Carrier will be implemented in the next step with a 5G smart module, which will be enable besides the higher performance grade, the seamless tracking and tracing across the supply chain.

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## LITERATURE

AFF+20 Assadi, A. A. et al.: User-friendly, requirement based assistance for production workforce using an asset administration shell design. Procedia CIRP 91, pp. 402–406, 2020.

AFF21 Ackermann, C.; Fechter, M.; Froeschle, P.: Thinking Innovation Ahead – Joint Semantic Modelling for Integrated Product and Production at the Research Campus Arena2036. In (Dröder, K.; Vietor, T. Eds.): Technologies for economic and functional lightweight design. Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 59–68, 2021.

Bar18 Bartmann, E.: IoT-Programmierung mit Node-RED. Elektor, Aachen, 2018.

BFD20 Bauernhansl, T.; Fechter, M.; Dietz, T. Eds.: Entwicklung, Aufbau und Demonstration einer wandlungsfähigen (Fahrzeug-) Forschungsproduktion. Springer Berlin Heidelberg, Berlin, Heidelberg, 2020.

BG15 Banks, A.; Gupta, R.: MQTT version 3.1.1. OASIS Standard, 29:89.

BHS20 Bozkurt, A.; Hagg, M.; Schulz, R.: Innovative logistics concepts for a versatile and flexible manufacturing of lot size one. Hannover Institutionelles Repositorium der Leibniz Universität Hannover, 2020.

BMK+19 Biesinger, F. et al.: A digital twin for production planning based on cyber-physical systems: A Case Study for a Cyber-Physical System-Based Creation of a Digital Twin. Procedia CIRP 79, pp. 355–360, 2019.

DIN89 DIN Deutsches Institut für Normung e.V.: DIN 30781-1:1989-05, Transportkette; Grundbegriffe. Beuth Verlag GmbH, Berlin, 1989.

EJT+21 Ewert, D. et al.: Assets2036 – Lightweight Implementation of the Asset Administration Shell Concept for Practical Use and Easy Adaptation. In (Weißgraeber, P.; Heieck, F.; Ackermann, C. Eds.): Advances in Automotive Production Technology – Theory


*Article is protected by German copyright law*

and Application. Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 153–161, 2021.

FAF+20 Fries, C. et al.: BMBF-funded research campus for the mobility of the future: Fluid vehicle production | Fluide fahrzeugproduktion, 2020.

FAT18 Fattah, H.: 5G LTE Narrowband Internet of Things (NB-IoT). Practical projects for the cloud and data… visualization. Chapman and Hall/CRC, Milton, 2018.

FD20 Fechter, M.; Dietz, T.: Bewertung der Wandlungsfähigkeit eines Produktionssystems. In (Bauernhansl, T.; Fechter, M.; Dietz, T. Eds.): Entwicklung, Aufbau und Demonstration einer wandlungsfähigen (Fahrzeug-) Forschungsproduktion. Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 11–17, 2020.

Fed18 Federal Ministry for Economic Affairs and Energy (BMWi): Details of the Asset Administration Shell: Part 1 - The exchange of information between partners in the value chain of Industrie 4.0 (Version 2.0). https://www.plattform-i40.de/PI40/Redaktion/DE/Downloads/Publikation/Details-of-the-Asset-Administration-Shell-Part1.pdf?__blob=publicationFile&v=3.

FHK+20 Freitag, M. et al.: Dynamics in Logistics. Proceedings of the 7th International Conference LDIC 2020, Bremen, Germany. Springer International Publishing; Imprint: Springer, Cham, 2020.

Fra06 Fraunhofer IAO: RFID – Anwenderbeispiel Volkswagen AG.

GSB17 Groß, E.; Siegert, J.; Bauernhansl, T.: Changing Requirements of Competence Building Due to an Increase of Personalized Products. Procedia Manufacturing 9, pp. 291–298, 2017.

Hag08 Hagebeuker, B.: Mehrdimensionale Objekterfassung mittels PMD-Sensorik. Optik & Photonik 1/3, pp. 42–44, 2008.

Hag21 Hagino, T.: Practical Node-RED Programming. Learn powerful visual programming techniques and best practices for the web and IoT. Packt Publishing, Birmingham, 2021.

HBK+19 Hofmann, C. et al.: The Impact of Routing and Operation Flexibility on the Performance of Matrix Production Compared to a Production Line. In (Schmitt, R.; Schuh, G. Eds.): Advances in Production Research. Springer International Publishing, Cham, pp. 155–165, 2019.

Hil12 Hilty, L. M.: Lokalisiert und identifiziert. Wie Ortungstechnologien unser Leben verändern. vdf Hochschulverl., Zürich, 2012.

Hil13 Hille, A.: Jahrbuch der Logistik 2013, 2013.

HNS20 Hagg, M.; Noortwyck, R.; Schulz, R.: Planen wir noch oder steuern wir schon? – Eine Analyse zur Abgrenzung von Planung und Steuerung. Wissenschaftliche Gesellschaft für Technische Logistik, 2020.

HS19 Hetterscheid, E.; Schlüter, F.: Morphology for Designing Cyber-Physical Systems in Supply Chain Planning and Control Processes. Logistics Journal nicht referierte Veröffentlichungen 03/2019, 2019.

HSD18 Hompel, M. ten; Schmidt, T.; Dregger, J.: Materialflusssysteme. Förder- und Lagertechnik. Springer Vieweg, Berlin, 2018.

HW10 Hülsmann, M.; Windt, K. Eds.: Understanding autonomous cooperation and control in logistics. The impact of autonomy on management, information, communication and material flow. Springer, Berlin, Heidelberg, 2010.

JB18 Janczewski; B. von: Datengold der Logistik: Neuer 5G-kompatibler Tracker macht Paletten intelligent. https://www.iml.fraunhofer.de/de/presse_medien/pressemitteilungen/Live-Palettentracking_DLK.html.

Joh19 Johannes Zeiler, J. F.: Architectural Design for Special Load Carriers as Smart Objects in a Cloud-based Service System. ICIEA 2019 April 12-15, 2019, Tokyo, Japan. IEEE Press, Piscataway, NJ, 2019.

Kag13 Kagermann, H., Wahlster, W., Helbig, J.: Recommendations for implementing the strategic initiative INDUSTRIE 4.0 securing the future of German manufacturing industry; final report of the Industrie 4.0 working group.

KKB+14 Kauffman, J. et al.: DyCoNet: a Gephi plugin for community detection in dynamic complex networks. PloS one 7/9, e101357, 2014.


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Klu10 Klug, F.: Logistikmanagement in der Automobilindustrie. Grundlagen der Logistik im Automobilbau. Springer, Heidelberg, 2010.

KSG21 Kessler, R.; Suske, J.; Gómez, J. M.: Einbindung von intelligenten Ladungsträgern in Prozesse der Intralogistik. In (Meinhardt, S.; Wortmann, F. Eds.): IoT – Best Practices. Springer Fachmedien Wiesbaden, Wiesbaden, pp. 209–222, 2021.

LBK15 Lee, J.; Bagheri, B.; Kao, H.-A.: A Cyber-Physical Systems architecture for Industry 4.0-based manufacturing systems. Manufacturing Letters 3, pp. 18–23, 2015.

LDL+17 Liao, Y. et al.: Past, present and future of Industry 4.0 - a systematic literature review and research agenda proposal. International Journal of Production Research 12/55, pp. 3609–3629, 2017.

Lep14 Lepratti, C.: Transparenz in globalen Lieferketten der Automobilindustrie Ansatze zur Logistik- und Producktionsoptimierung. Wiley, Hoboken, 2014.

LFK+14 Lasi, H. et al.: Industry 4.0. Business & Information Systems Engineering 4/6, pp. 239–242, 2014.

MBV18 Müller, J. M.; Buliga, O.; Voigt, K.-I.: Fortune favors the prepared: How SMEs approach business model innovations in Industry 4.0. Technological Forecasting and Social Change 132, pp. 2–17, 2018.

Pal20 Palacios, J. O.: Tool for identification and report of network assets and services based on traffic analysis and operating systems fingerprint.

Pop18 Popp, J.: Neuartige Logistikkonzepte für eine flexible Automobilproduktion. Dissertation, Stuttgart, 2018.

RSJ+19 Reinhard Geissbauer et al.: Digital Product Development 2025, 2019.

SBT+08 Scholz-Reiter, B. et al.: Load carrier management on ro-ro terminals 1, pp. 274–279, 2008.

Sch15 Schenk, M.: Produktion und Logistik mit Zukunft. Springer Berlin Heidelberg, Berlin, Heidelberg, 2015.

SP17 Schweitzer, H.; Peitz, M.: Datenmärkte in der digitalisierten Wirtschaft: Funktionsdefizite und Regelungsbedarf?, 2017.

VBH17 Vogel-Heuser, B.; Bauernhansl, T.; Hompel, M. ten Eds.: Handbuch Industrie 4.0. Bd. 4: Allgemeine Grundlagen. Springer Vieweg, Berlin, 2017.

Wat16 Watkiss, S.: Learn electronics with Raspberry Pi. Physical computing with circuits, sensors, outputs, and projects. Apress; Distributed to the book trade worldwide by Springer Science+Business Media, New York, New York, New York, NY, 2016.

WXV+20 Wei, F. et al.: Entwicklung eines intelligenten Logistik- und Bestandsmanagementsystems auf Basis von Internet der Dinge Technologien. Logistics Journal Proceedings 12/2020, 2020.

ZF20 Zeiler, J.; Fottner, J.: Implementierung und Test eines Service-Systems mit intelligenten, modularen Sonderladungsträgern. Wissenschaftliche Gesellschaft für Technische Logistik, 2020.

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