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Development of a Cyber-Physical Logistics System in an *Industrie 4.0* Environment

Master Thesis

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Subject of study: Business Administration and Engineering

[redacted]

Confidential

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Hanover, 31. March 2017

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1 Introduction

This thesis „Development of a Cyber-Physical Logistics System in an *Industrie 4.0* environment“ has a detailed look on intelligent systems to gain the maximum efficiency within manufacturing processes. The focus of this thesis is on logistics, to ensure the replenishment of material at the machine to keep the production process smooth. This thesis is a cooperation between Institut für Wirtschaftsinformatik and Continental Reifen Deutschland GmbH.

1.1 Motivation

The worldwide competition in manufacturing is pushed by innovations in production and logistics. However, this is not the only challenge. Shorter product life cycles, increasing variety of versions and last-minute production program changes due to the customer are the new challenges. Based on the requirements of quick realization, the current trend to an *Industrie 4.0* factory combines information technology and engineering.[1] The idea is to make decentralized decisions. The newest information and communication technologies allow a machine-to-machine communication, which has the highest expected growth rates. Nevertheless, there are also combinations like business-to-machine and customer-to-machine or the other way around possible. [2]

Therefore, the intention of this thesis is to compare such technology with the production and logistics processes. An example would be that production machines are communicate directly with transportation vehicles. Thus, the material flow can be automatically controlled and bottlenecks avoided. CPS summarize a combination like this.

The complete topic CPS is still new in a production and logistics environment. This thesis has a detailed view on CPS in a production and logistics environment for manufacturing. It also has a look on the ability to act in a proactive way to the logistical challenges between production stages, thus achieving sustainable growth with maximum efficiency.

1.2 Practical Relevance

The majority of the Continental tire plants were built a long time ago. Therefore, their structures, technology, fabric layout and IT-systems are not completely updated. They cannot compete with the fast growing and changing technical progress and

[1] Cf. Fraunhofer-Institut für Produktionstechnik und Automatisierung (IPA) 2015, p.4
[2] Cf. Heimann 2015

innovations. An additional challenge represent the production processes. The plants do not have the same amount of machines and production processes in detail. In general, the production process is the same, also described in Chapter 3.2. Nevertheless, the tasks belonging to the production are different from plant to plant.

Processes and technology can be changed only systematically. One reason are the costs. The return of investment is often given after years or it is not possible to calculate them. For example, a machine can be replaced by another. The new machine is faster and the output is higher. In this case, it is easy to calculate the benefit. However, a process change as an implementation of an IT system instead of paper work will maybe not change the output and the personnel is now used for maintaining the IT system.

Because of the slow process and technology change, it is significant to have a fast communication network and all information available everywhere and every time. This previous mentioned reality requires a solution. Therefore, a CPS would enable a connection of production, logistics and employees within one system. The focus is on networking several independently devices.[3]

Hence, the following Figure 1 illustrates the ideal three interconnection ways in a tire manufacturing plant referring to a cyber-physical world.

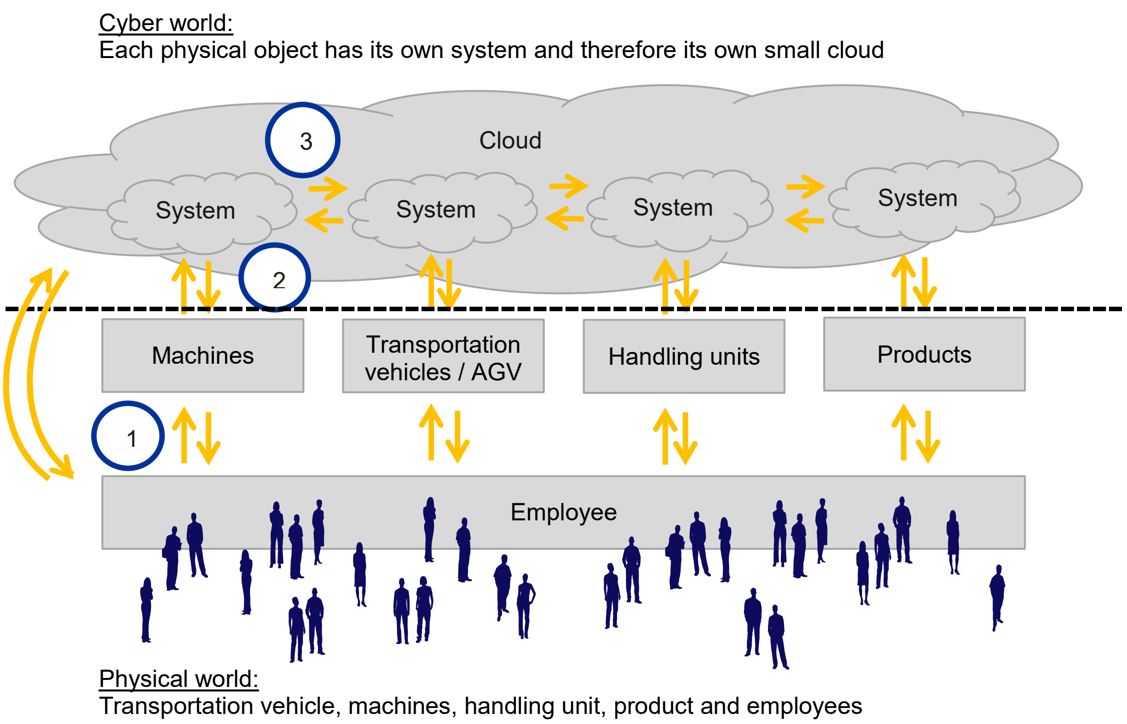

Figure 1: Ideal interconnection ways in a cyber-physical world

[3] Cf. Jazdi 2014 p.1

The first interconnection way is object-to-human and vice versa. The objects are transportation vehicle, machine, handling unit and the product in case of a tire manufacturer. Nevertheless, the objects and the humans are both mentioned as physical objects in this thesis. Therefore, it is to mention why this sub differentiation exists. In the beginning of the evolution towards Cyber-Physical System, it started with humans are able to move objects (automotive, aviation, railway). The second step was moving data (telephone, internet) and finally the direction goes into data moves objects, so that the human it not directly involved anymore.

The second one is between the cloud, respectively the systems, and the physical object. The condition to realize this are smart objects. They need to be able to act and to communicate between each other.

The third interconnection ways goes one-step further. That means the objects of one group can communicate and act with an object of another group. In addition, a full information access between the clouds must be ensured.

The following Figure 2 shows how the interconnection ways in Continental look like.

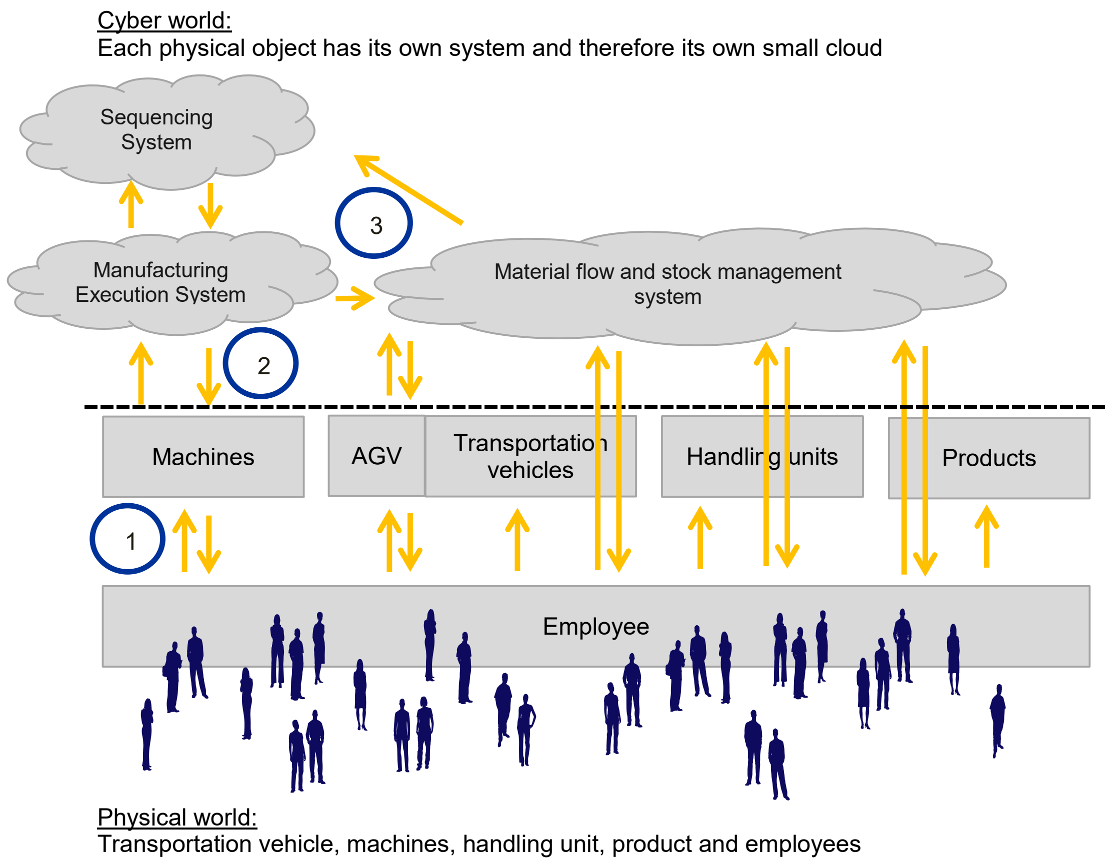

Figure 2: Initial situation of interconnection ways in a cyber-physical world at Continental

As it can be seen in this illustration, not all interconnection ways are realized. The status is, that human are still moving objects. They receiving, for example, the information of SAP EWM which handling unit needs to be moved, but a direct connection between SAP EWM and the HU is not given.

Overall, a detailed look needs to be done, how the initial situation can be developed to the three ideal interconnection ways in the complete plant.

1.3 Objective

The aim of this thesis is to develop a CPS for the logistics in a tire manufacturing environment. The research questions help to identify the possibilities of Continental Reifen Deutschland GmbH to use CPS in an *Industrie 4.0* environment.

Therefore, the main research question is: Why and how are Cyber-Physical Logistics Systems able to improve a manufacturing environment?

To answer this question, the thesis has three different detailed views on this topic based on the previous mentioned three interconnection ways. Therefore, each view has a more specific research question. In summary, the research questions of each view are established as follows.

The first detailed view is on physical objects and the specific research question is: How can physical objects become smart objects to be a part of a Cyber-Physical Logistics System in a tire manufacturing environment? The intention is to identify the physical objects, which can be improved to smart objects regarding the connection to the cyber world. This view concentrates on the objects, how each of them can become smart to enable the three communications ways.

The second detailed view is on the batch production using the example of passenger light truck tires and the specific research question is: How does a Cyber-Physical Logistics System improve the material flow for the batch production with intermediate semi-finished goods stock? The reason why is, that the tire building machines have sometimes lack of material, which causes less output. This view concentrates on the interconnection between system and employee in the first step and in the second step between system and system, respectively object to object.

The third detailed view is on the one-piece production using the example commercial specialty tire and the specific research question is: How does a Cyber-Physical Logistics System improve the material flow for the one-piece production with just-in-time delivery? The intention is to realize a higher utilization of the presses in curing and therefore more output. This view concentrates on the choice of systems, as well as how to interconnect the system with the physical objects.

1.4 Approach

This thesis focuses on specific and important logistics topics in passenger light truck tire (PLT) and commercial specialty tire production (CST), because of the limited time of six months. To address the previous mentioned research questions the thesis is structured as follows.

1 Introduction

This chapter illustrates the motivation, the practical relevance and the objective of this thesis. Within the research, the topic Cyber-Physical Systems is still new and not really applied on the logistics processes within a tire manufacturing environment. In addition, some challenges of Continentals tire production regarding fast growing and changing technical progress and innovations are mentioned. Finally, the research questions are established.

2 Fundamental Principles of the *Industrie 4.0*

This chapter presents the fundamental principles. It starts with the overall topic the forth-industrial revolution and its technologies. Afterwards the thesis focuses in detail on the topic Cyber-Physical Systems. The chapter finally ends with a closing discussion and derivation of the research gap.

Therefore, the research question is: Why and how are Cyber-Physical Logistics Systems able to improve a manufacturing environment?

3 Analysis of Logistics in Tire Production

This chapter explains the tire production in more detail by presenting an overview of Continental tires. Afterwards, the types of tire production are explained and compared, which are important for this thesis. Finally, the material flow system using the example passenger light truck tire is described.

4 Development of a Cyber-Physical Logistics Systems in Tire Production

This chapter answers the proposed specific research questions based on highlighting the problem, pointing the solutions up, illustration of the initial situation, development of solutions and ends with first results. This is done for each of the three views to distinguish this thesis to study why and how Cyber-Physical Logistics Systems are able to improve a manufacturing environment.

5 Comparison, Discussion and Recommendation

In this chapter, findings of the three specific research questions are summarized in order to start further comparison and discussions, as well as a recommendation of Cyber-Physical Logistics Systems in manufacturing environment.

6 Limitations

This chapter sums up the limitations, respectively the current challenges, regarding Cyber-Physical Systems in a tire production, in this case of a batch and one-piece production. Additionally, general barriers in production and logistics are decribed as e.g. safty and secuity.

7 Conclusions and Outlook

At last, this chapter points the highlights of this thesis out and recommends further research approaches regarding the previous shown limitations.

7 Conclusions and Outlook

After analyzing the current plant and process situation of a tire manufacturer, regarding the use of CPS in logistics, it was possible to develop and suggest, how the existing CPLS in the batch production with semi-finished intermediate good stocks can be extended and how a CPS can look like in case of the one-piece production with just-in-time delivery.

First, the physical objects in a tire plant were identified and analyzed based on the literature about physical objects in a CPS (Chapter 2.4.1). Additionally, suggestions were made how to develop them to smart objects, so that actions can be triggered due to the cyber world.

The other big topic was the analysis of the material flow in two different types of tire production. The problems in both were identified.

1. The losses through lack of material at the tire building machines in the batch production with semi-finished intermediate good stock was one of them. A proposal for a Cyber-Physical System by alerting was done. Thereby, two versions were described, an alerting to an employee and an alert directly to the system respectively to the physical objects of the systems.

2. The other problem was the low utilization of the presses in the one-piece production with just-in time delivery and the push principle between two productions stages. After changing the principle to a pull production, the optimization criteria were defined and the relations of the material flow illustrated to have a foundation to decide about the CPS. Furthermore, a mathematical model was established. Finally, specific suggestion for developments of the physical objects were made to enable an interaction with the cyber world.

This thesis paves the way for a fully connected smart factory, with the goal of a customizable one-piece production, due to the analysis of CPS usage for the material flow within the production and an equipment check of the physical objects regarding smart objects in a tire plant.

The future Cyber-Physical Systems within production should be able to react to changes in the market or supply chain happen in real time.[113] Even better, it should be able to react across plants. Nevertheless, the production process needs to be fully

[113] Cf. acatech 2011 p. 23

connected and a customized one-piece production possible before, to realize this future.

The following part describes the research approaches regarding the limitations of Cyber-Physical Logistics Systems, presented in the previous Chapter 6.

1) Introduction of a CPS and the belonging smart objects:

   A roll out strategy, which fits to the introduction of CPS, is to find. Different types of roll out strategies exist, for example step-by-step and big-bang.[114] In addition, a complete procedure model is to develop to realize a smooth change process.

2) Defining standards[115]:

   This topic has a high research approach. The definition of standards includes terms, technology and IT. One approach could be the development of a dictionary, based on terms of CPS or *Industrie 4.0*. Another approach can be the analysis of different existing CPS, the suggested operating places, as well as the advantages and disadvantages of each system. Furthermore, it can be analyzed which smart objects should be used for which CPS.

3) Training and qualification of employees:

   It is to find the content of such a training and if it is possible to get an official qualification. Regarding that, which topics are included, because *Industrie 4.0* and CPS are open terms?

4) Link within CPS:

   The scenario is the following: a group of smart objects has a break down, for example the AGV. Now the production machines are affected, as they run out of material. Therefore, the approach is to analyze the link between physical and cyber world, as well as a strategy to have a backup solution for each system.

5) Safety:

   Research on safety of smart objects regarding humans need to be done. It is to find out what are the dangers, how to avoid them, but also how to validate the safety status of a CPS.

[114] Cf. Becker et al. 2003, p. 271
[115] Cf. VDI/VDE-Gesellschaft Mess- und Automatisierungstechnik (GMA) 2013, p.7

6) Security:

   Security of data, information and communication is to ensure. An analysis about how to protect the network against hacker attacks and data stealing. Therefore, appropriate steps regarding security architecture, protective measures as well as validation methods are necessary.[116]

7) Decentralization of information and data moves object:

   The last approach is to analyze how the vision of *Industrie 4.0* can be implemented in a batch production. To remind, the vision is, that the product knows its production plan and can navigate through the production by itself. In the literature, the example car production is used, but this is a one-piece flow, in which the car is build up systematically. Therefore, how does it look like for a batch production, in which the components build the product in a later production step?

[116] Cf. VDI/VDE-Gesellschaft Mess- und Automatisierungstechnik (GMA) 2013, p.7