Making Industry 4.0 functionalities understandable based on the production of a model car

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Abstract. At the University of Applied Sciences Würzburg-Schweinfurt, Faculty of Mechanical Engineering, an Industry 4.0 use case was implemented with the c-factory, the so-called concept factory. This use case consists of building an individual model car. The focus here is not on the model car, but rather on mapping the entire product life cycle and the Industry 4.0 functionalities during the production. These are, as identified at the FHWS/FM: networking, the Internet of Things, flexible production, human-robot-collaboration, augmented reality, additive manufacturing and Big Data. The foundation stone was laid as part of a student project and, with its unique form of enabling didactic, serves not only to demonstrate and understand Industry 4.0, but also ensures that all participants take on the role of both learner and teacher. Through this, both sides support each other in expanding the use case and hereby broaden their own (educational) horizons.

1. Industry 4.0 at the University of Applied Sciences Würzburg-Schweinfurt

When people, machines and industrial processes are intelligently networked, we speak of Industry 4.0. Connecting production to state-of-the-art information and communication technology enables highly customized products on customers’ requests instead of a fixed set of possible customizations. With the help of the Internet of Things, not only information is displayed, but also communication between devices and humans is made possible [1].

There is a clear trend towards individualization of products which requires flexible production processes. In the future, tasks will be completed jointly by humans collaborating with robots. Through additive manufacturing parts can be produced individually, for instance in geometric shapes that were previously impossible to create. Augmented reality joins the real world with the virtual world, e.g., to simulate new products in a familiar environment. Big Data is concerned with the management and interpretation of the data generated in each of these aspects.

With its i-factory, the University of Applied Sciences Würzburg-Schweinfurt (FHWS) wants to demonstrate an intelligent factory based on four pillars: digital innovation, digital intelligence for technical flexibility, digital integration and digital inclusion in the field of human resources. The concept-factory, the so-called c-factory, was established in the Faculty of Mechanical Engineering (FM) to show an Industry 4.0, i.e. the construction of a customized model car. The c-factory was developed in the context of a student project.

However, the focus here is not on the model car as such, but on mapping the entire product life cycle and the technical Industry 4.0 functionalities during production. These are (as mentioned above):
networking, the Internet of Things, flexible production, human-robot-collaboration, augmented reality, additive manufacturing and Big Data (figure 1).

The technical dimensions of Industry 4.0, as identified at FHWS/FM.

Figure 1. The technical dimensions of Industry 4.0, as identified at FHWS/FM.

The production of the model car demonstrates how these dimensions are applied in the c-factory. By personally carrying out these individual production steps, the user gains a much better understanding of the processes, their digitalization and implementation and their significance. In the conception of the case, special care was taken to include devices from different manufacturers in the process to meet the challenges of today’s technology, as different standards and interfaces are still state-of-the-art today [2].

2. The use case
The c-factory realized a specific application to implement the technical functionalities of Industry 4.0 in a “hands-on” scenario by producing a small model car, a pick-up truck, which can be configured in almost any way, using various manufacturing processes. The truck has three components that are produced on site. The truck’s cabin is injection molded, the chassis is milled individually and the loading area is printed three-dimensionally (3D). There are eight steps the user must follow in order to receive a finished product. These are: identification, configuration of the model car, sending the configuration to the cloud, using the transponder to start production, manufacturing and assembly of the vehicle, then doing the quality and functional checks (figure 2).

At the beginning, there is the identification at the system in order to configure a pick-up truck. There is a selection of the previously mentioned components: a small and a large cabin, a short and a long chassis and a single or double rear axle for the truck. Based on this selection, six possible standard versions can be created (figure 3).
However, the customer is given the opportunity to further individualize his self-configured vehicle by designing an individual loading area with the help of computer-aided design (CAD) software. Once this process is completed, the created configuration is given its own identification number (ID), which is made available as a quick response (QR) code. The configuration is stored in the cloud and linked to a transponder. The transponder is later needed to trigger the production of the components. Only the selected components during the configuration are produced on site, whereas additional elements, that are required to complete the vehicle, are purchased parts such as axles and screws. Each of these components is produced differently. The chassis is milled, the cabin is injection molded and the loading area is printed in 3D. Once all required components have been produced, the vehicle can be assembled by the user at the designated station. This step is guided virtually with the help of augmented reality glasses. Light signals are used to point where the needed parts are located, while the glasses show an animation to demonstrate the assembly procedure. This is followed by a quality and then a functional check. Once the vehicle passes both checks it may be released to the customer.

3. The process in detail
As already mentioned, a transponder is used to request the required data for each production step. Therefore, the customer can carry out the production of the truck independently and without the support of trained personnel.

3.1. Preparatory steps
As mentioned above, everything starts with the user’s identification on the system and the vehicle is given a name. Afterwards the configuration process starts, where the user can select a cabin, a chassis and a loading area for the pick-up truck. The cabin can be short or long, the chassis short, long or long with a double rear axle. With these variations, either a suitable standard loading area is suggested, or an individual one can be chosen. Such a loading area is designed in an extra step and must be printed separately in 3D. After all components have been selected, the configuration is saved in the cloud and is also assigned its own identification number (ID), which is immediately displayed on the monitor in the form of a QR code that leads to the vehicle’s own website.

A truck was created to better understand every production step in the c-factory. In this example, the truck was given a king-size cabin (“Kabine” in German), a deluxe chassis (“Chassis” in German), a
double-rear axle ("Achse tandem" in German) and an individual loading area ("Ladefläche individuell" in German).

The configured pick-up truck was named "CoSME2020". Before finally saving the configuration, an overview of all selected elements was displayed for the user. By pressing the "zurück" button (German for "back"), the user could re-start the configuration process. By pressing the "speichern" button (German for "save"), a communication with the cloud was established (and thus to the database) and the entered data was saved (figure 4).

![Figure 4](image_url)

**Figure 4.** Screenshot of the configured vehicle with its selected components (king-size cabin, deluxe chassis, double rear axle and individual truck bed).

The vehicle was then assigned its unique chassis number, which was displayed on the screen as a QR code (figure 5).

![Figure 5](image_url)

**Figure 5.** Screenshot of the created QR code for the configured vehicle.

When scanned, the code guides the user to the vehicle’s own website (figure 6). Since nothing has been produced yet, only the “configuration” button is highlighted and the selected components, the chosen name and a time stamp are listed.
The highlighting of the buttons serves as a visual indication of which steps have already been carried out. An orange button, as the “configuration” button in figure 6, indicates that the step has been completed, whereas grey buttons stand for not yet completed production steps.

**Figure 6.** Screenshot of the model car's website immediately after its configuration.

This step creates an understanding of flexible production and networking. A gradual introduction to the topic, which illustrates the variety of products with a simple example, is well-suited to introduce both students and visitors to the topic of Industry 4.0.

Scanning the QR code with your own smartphone also demonstrates that devices are indeed networked with each other and that the configuration is sent to the cloud.

### 3.2. Production of the model car

Once the configuration has been made, production can begin. Now the transponder is needed in order to start manufacturing the chassis, cabin and loading area. First the chassis is produced. As mentioned before, there are three different versions possible: short, long and long with double axle.

Depending on the version, the drill holes for the axle brackets and screws must be positioned differently. The vehicle’s ID and name are also engraved. All data are automatically transmitted to the milling machine with the help of the transponder. Communication with the database is established, and the required information for the milling process is transferred and entered into the G-code program (programming language to control automated machine tools like milling machines). The handling is done by a robot arm, which also needs to know whether to pick a long or a short chassis that is to be inserted into the milling machine (figure 7).
As mentioned above, there is constant communication between the computer that controls the milling machine and the robot. It must be ensured that the correct chassis is milled according to the configuration. It also must be ensured that after the front side is finished, the door of the milling machine is opened so that the robot can turn over the part. When this operation is done (and the robot is outside of the machine), the door must be closed again, and the machining of the back side must be started. When this operation is finished, the door must be opened again so that the robot can remove the chassis and present it to the user for a visual quality check. Then the user can decide whether it is a good part or a reject. Afterwards, the resulting data is saved and made visible on the website (figure 8).

**Chassis:**

| Milling Time Front Side: | 12.96 min |
| Milling Time Back Side: | 2.24 min |
| Cutting Speed: | 7 m/s |
| Feed: | 7 mm/s |
| Quality Check: | passed |

**Figure 8.** Excerpt from the vehicle's website, showing the production data of the milling machine.
The cabin is the next required element. Analogous to the milling machine, communication to the database is established to obtain the necessary information. In this case the cabin size is transmitted, i.e. small or large cabin, the vehicle’s name and ID. After the cabin has been injection molded, a QR code and the vehicle’s name are written by laser on the cabin’s roof. Afterwards, the cabin is dispensed via a conveyor belt (figure 9) and shown on the website (figure 10).

![Handling robot placing an injection molded cabin on a conveyor belt.](image)

**Figure 9.** Handling robot placing an injection molded cabin on a conveyor belt.

**Cabin:**

- **Injection Pressure:** 750 Pa
- **Residual Cooling Time:** 65 s
- **Cycle Period:** 120 s
- **Quality Check:** passed

![Excerpt from the vehicle's website, showing the production data of the injection molding machine.](image)

**Figure 10.** Excerpt from the vehicle's website, showing the production data of the injection molding machine.

Finally, the loading area is produced. Standard loading areas are produced in stock and can be found at the assembly site, whereas individual loading areas must be designed first. The designing process can also be started by using the transponder. Again, communication with the database is established to ensure that the designed element will fit and can also be mounted on the corresponding chassis (cut-outs and mounting holes must match). A CAD module is started, where the corresponding standard loading area is loaded. Based on this loading area, individual changes such as length, width and height can be made. Furthermore, the user can add labels and change the shape of the rear lights (figure 11).
Figure 11. CAD module for the individualization of loading areas, the corresponding standard loading area can be seen.

A few modifications have been made for this example. Firstly, the loading area is narrower than a standard one. Figure 12 shows that while the loading area is transformed, the wheel arch hasn’t been changed. This is due to the logic that ensures that important elements must not be altered.

Additionally, the shape of the rear lights has been changed, they are round in the final version. Furthermore, a label has been added, namely “Brasov”.

After saving this individual loading area, all data (length, width, height, label and shape of the rear lights) was transferred to the database, as they not only serve to complete the data set but are also required later during quality inspection.

Both individual and standard loading areas are 3D printed.

Figure 12. The finalised loading area. It is narrower than standard ones, and a label "Brasov" has been added to one side.

Figure 13. The designed loading area during 3D printing. An NFC chip was inserted.

However, the printing process is briefly interrupted to allow near-field communication (NFC) chips to be inserted (figure 13).
After the printing process is finished, all production data such as duration, used printer, material, color, time stamp and batch are stored in the cloud and assigned to the NFC chip. Therefore, the production data of each loading area can be tracked as well.

As their production time varies, cabins, chassis and loading areas must be stored, so they are neither mixed up nor lost. Their storage and transport is carried out by robots (figure 14). An autonomous robot brings the designated elements to the storage station and from the storage station to the assembly site.

![Figure 14. Students observing an autonomous robot transporting parts to the storage location. Photo credit FHWS.](image)

Once again, the transponder is needed for the identification at the system. Based on the ID, the user can store or retrieve a cabin, chassis, loading area or a pick-up truck. Every transaction is handled by a small robot.

This step demonstrates modern production conditions to students and/or visitors. The worker does not have to create each order individually, as these are automatically transmitted to the production unit via the network. Handling robots support humans by taking over dangerous or difficult tasks. The human is not replaced, but supported and assumes the role of the supervisor and decision maker (good part/rejects).

3.3. The quality and functional checks
After all components have been produced and made available, the user can assemble the pick-up truck. Light signals as well as an augmented reality-based assembly instruction help with the completion. The light signals show where purchased parts or the self-produced components are located. The assembly aid is made possible with the Microsoft Hololens, an augmented-reality headset. The user is not only informed where the required parts and tools are located, but every single action is demonstrated (figure 15). The picture shows an extract from the assembly guide. The user is informed by colored rectangles where the axle should be positioned, whereas the small circle indicates where the user is looking.
Now the quality inspection can be carried out. This is the first step in the production chain, where the transponder isn’t needed, as the machine can interpret the QR code on the cabin’s roof.

A database query provides the required information for the inspection, such as the vehicle’s dimensions based on the selected elements. This allows the machine to carry out an automated target/actual comparison. As mentioned above, the dimensions of the individual loading area are also transmitted to the database.

Thus, the quality checks of vehicles with individualized loading areas can also be carried out automatically, as the target data is made available. The result of the test is automatically transferred to the cloud including the measured values (figure 16) and the taken images (figure 17).

**Quality Check:**

| Check Time: | 06-06-2020 17:21:11 Uhr |
| Assembly: | Correct |
| Errors: | None |

**Measured Values:**

| Length Vehicle: | 125.08 mm |
| Length Truck Bed: | 525.70 mm |
| Width Truck Bed: | 36.01 mm |
| Height Truck Bed: | 17.00 mm |
| Length Cabins: | 28.05 mm |
| Number of Axles: | 3 |

**Figure 16.** Excerpt from the website showing the result of the quality check and the measured values.
The last step is a functional test on the inclined plane. The vehicle’s speed is measured and a photo is taken. The data, consisting of measured values (figure 18) and image taken during the test drive (figure 19), are stored in the cloud and can be accessed via the vehicle’s own website. As already mentioned, both testing machines are able to interpret the printed QR code in order to generate queries to the database, which return the target data. Consequently, the test results are also saved and made available in the cloud.

**Functional Check:**

| Check Time: | 08-06-2020 17:20:54 Uhr |
|-------------|-------------------------|
| Check:      | OK                      |

**Test Values:**

| Average Speed: | 0.74 m/s |
|----------------|----------|
| Maximum Speed: | 0.83 m/s |

**Figure 18.** Excerpt from the website showing the result of the functional check.

**Figure 19.** Picture of the vehicle, taken during the functional check.
This step demonstrates modern testing methods, which enable several quality feature checks within a short period of time, as they are suitable for both serial and flexible production. Students are taught how important coding skills have become nowadays. This simple example shows the following: a QR code is read in and a database query is generated. In return, the database must provide the corresponding target data to the test machine. The machine records the actual data and compares it to the provided target data. Then, a decision must be made on good part or reject, according to preset tolerance ranges. And this must take place within few seconds. In order to do so, the machine must be programmed to carry out all of these steps.

3.4. Monitoring the production

All production progress can be tracked on the vehicle’s own website, as the machines report their status back to the cloud/database. In addition to the vehicle’s configuration data, all production data that has been generated during the manufacturing of the cabin, chassis and loading area are stored and displayed. Likewise, not only the results of the quality and function tests are displayed, but all created images as well. The user can not only read the facts but also see how the checks have been performed based on the provided images.

This step demonstrates a transparent production. The user can remotely access the production data and status of the self-created and configured vehicle at any time. Furthermore, the user can also follow the production progress and also review the generated data. Thus, the vehicle does not only transport a storyline, but also a small piece of traceable and understandable Industry 4.0.

4. Conclusion

The c-factory uses the production of a model car to better illustrate Industry 4.0 functionalities. How were these implemented? About networking: all machines are connected to the cloud and there is a bidirectional data flow, as data can be both written and read. The Internet of Things was realized in the vehicle’s own website. Process information and progress can be viewed by accessing the corresponding website. Since the model car can be customized in many ways, a flexible production is guaranteed. The loading area of the vehicle is 3D printed and thus the additive manufacturing was implemented. The production is supported by different handling robots, they provide both safety (risk of injury) and assistance by transporting and storing the components. At the assembly station, the user is guided with the help of augmented reality glasses so that the car can be assembled without difficulty. All process and production data are collected and evaluated, yet given the relatively small amount of data, one cannot quite speak of Big Data.

The c-factory is not only reserved for students and lecturers, but also gives visitors from industry and trade the opportunity to reflect in workshops on the necessary skills for professional activities in the field of Industry 4.0.

Students were responsible for the technical implementation of the c-factory, from the creation of the digital twin to the commissioning of the machines and writing the necessary software. The c-factory is constantly being further developed in student projects across faculties in order to add more functionalities, such as business processes. In doing so, the c-factory acts as an inclusive knowledge incubator for both lecturers and students, for supervisors and tutors. The lecturers take on the role of coaches and by expanding the project, both sides benefit from the added content and their expanded knowledge horizon.

The c-factory’s didactic concept won the prize “Best Machine House 2019” of The Mechanical Engineering Industry Association (VDMA). The jury was impressed by the teacher’s willingness to take on a completely new didactic approach and thus question the previous teaching, while the students work in a realistic industrial environment to physically and digitally map the lifecycle of a technical product [3].

Furthermore, the c-factory was selected as a development and application environment for small and medium-sized companies (SMEs) by the so called “I4KMU” project, which is founded by the German Federal Ministry of Education and Research (BMBF). SMEs face challenges in the
implementation of new concepts and ideas in the field of Industry 4.0, as they lack the structure of larger companies. They do not have the test environment and not enough personnel for the extensive application process to obtain funding. Thus, the c-factory has successfully achieved the classification as an Industry 4.0 test environment and can provide professional support to SMEs [4].

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