PROJECT FINAL REPORT

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4.1 Final publishable summary report

4.1.1 Executive summary

Factory-in-a-Day was aimed at improving the competitiveness of European manufacturing SMEs by removing the primary obstacle for robot automation; installation time and installation cost. The high costs result in payback periods, making the investment in robotized automation economically unattractive. Factory-in-a-Day has helped reduce the installation time (and the related cost) by bringing together hardware, software, and business innovations with a diverse project team consisting of academic partners (TU Delft, TU Munchen, KU Leuven), research institutes (Fraunhofer IPA and IPT, CNRS-LAAS), large companies (Philips, Randstad, Siemens, Materialise, Universal Robots) and SME's (Lacquey, FactoryControl, EMP Tooling, Delft Robotics, PAL robotics). All of the project milestones and results have been reached according to plan. Below, the most salient events and results are highlighted per workpackage.

In Workpackage 2 we aimed to develop the business models and standards and certifications that are necessary for practical implementation of the factory-in-a-day robots. Various business models have been analysed and as a result the spin-off company Delft Robotics was started, which later became a partner in Factory-in-a-Day. Temp agency Randstad determined the requirements and created the blueprints for setting up a combined robot/human rental/temp agency, and various Factory-in-a-Day partners contributed to the new ISO/TS 15066 standard for collaborative industrial robots.

Workpackage 3 focused on robot system hardware, resulting in a patented gripper design, a library for quick design of 3D printed robot grippers, 3D printed polishing tools, and a Workplace Simulation Tool for quick assessment of the customer requirements. All of these results help speed up the installation process of new industrial robot systems.

The goal of Workpackage 4 was to create robot arms that are aware of all (dynamic) obstacles in their environment, and that respond by moving around these obstacles while still continuing their work. This resulted in several integrated systems for Philips, one by Siemens (who quit Factory-in-a-Day after 18 months due to severe internal reorganizations), reactive motion planning demonstrators by CNRS-LAAS. Additionally, we delivered an Augmented Reality system to transmit robot intentions to human coworkers, in order to reduce unintended motion obstructions. Arguably the most visible result was winning the first prize at the Amazon Picking Challenge 2016. These innovations in automated 3D vision and motion planning makes it quicker to install a new robot system because the programming time is significantly reduced.

The focus of Workpackage 5 was on learnable skills, i.e., to make it easy and fast to teach robots how to execute a new task. An extensive list of scientific publications has resulted from this work, demonstrating how the robot understands the order of execution and learns the proper motions after only a few examples from a human. Simultaneously, Universal Robots developed the UR+ programme (later commercialized into their UR Caps programme) which allows easy connection and integration of hardware and software components into a full robot system.

Workpackage 6 was fully aimed at a framework of software tools for the rapid installation of new robot systems. Through the work in this workpackage, we have achieved a leading position in the internationally accepted standard framework ROS-Industrial, as evidenced by our coordinatorship of the new H2020 project "ROSIN: ROS-Industrial Quality-Assured Robot Software Components".

All technical innovations were brought together in a series of 'robothons' (2-day focused development events) and a dozen demonstrators in Workpackage 7, disseminated through over 40 scientific publications and more than 200 dissemination activities (exhibitions, presentations, press articles, etc.) in Workpackage 8.

4.1.2 Summary description of project context and objectives

This section contains the project context and objectives. The text is adapted from the text in the original Description of Work.

The problem

Factory-in-a-Day aimed at reducing the installation time of a new hybrid robot-human production line, from the weeks or months that current industrial systems now take, down to 1 day. The ability to rapidly install (and reconfigure) production lines where robots work alongside humans, will strongly reduce operating cost and open a range of new opportunities for industry – especially manufacturing SMEs – to implement robotic systems which improve productivity, flexibility and competitiveness, while strongly reducing investments and pay-back times.

Typically, a robot installation in a traditional industrial setting used to take 3 months and often more, when measuring the time between first customer contact up to full operability. In optimistic cases it may take about 3 months (roughly 100 days). A survey preceding the Factory-in-a-Day project showed that the long installation time (and associated cost) was the main reason for SME's to *not* invest in robotics, because their production batch sizes are too small to justify the investment, see Figure 1. This project therefore targets a 100-fold improvement over current industrial practice, which would benefit not only large industries looking for additional flexibility in their production lines, but particularly to SMEs who will be able to take advantage of the enhanced productivity and much-improved return-on-investment.

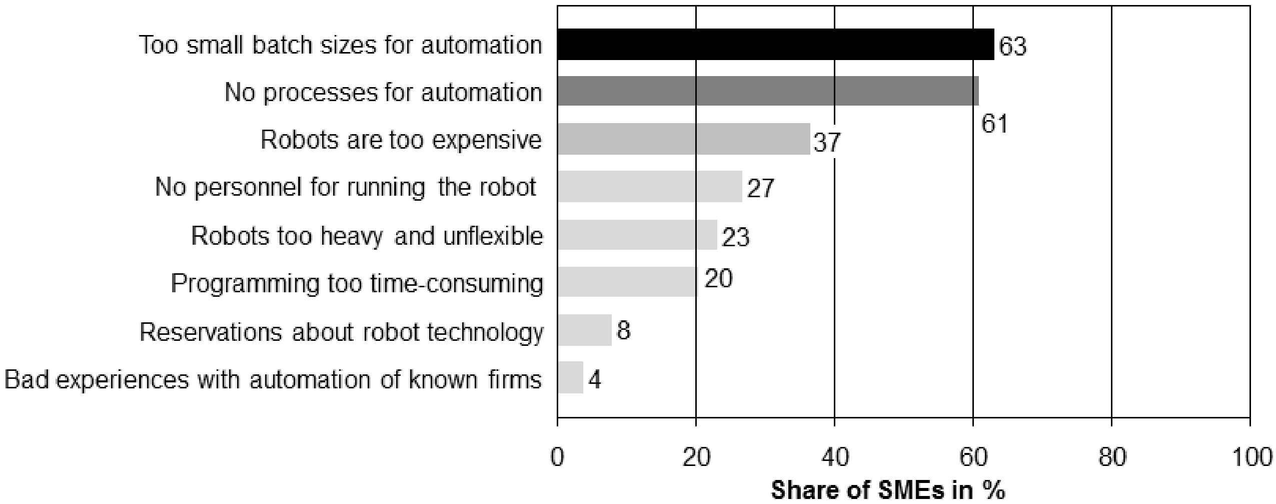


Figure 1: Main reasons for SMEs for NOT investing in robotics (Survey amongst 301 SMEs)[2].

Objectives

The objective of this project is **to marginalize the system integration cost by reducing the system integration time to one single day**. The resultant 50% price reduction of fully integrated systems is not even the main effect. The really significant impact will be that the SME's no longer have to earn back the investment through only one of their short production batches. In one day, the machines can be re-installed for another temporary product line and continue to be useful. To achieve this radical improvement in installation times, the project will bring together, develop to near-market stage and integrate a number of key technology innovations under development at project partner organisations, that will make a 'Factory-in-a-day' concept fully realizable within a few years. The

[2] Fraunhofer ISI survey 2008

development of these core technological breakthroughs in parallel to the organizational innovations they enable, are the main goal of this project and will radically change the robot automation sector and be a key driver for improving the competitiveness of European manufacturing SMEs.

The key breakthrough technologies are:

1. Safe robot arms with novel proximity-sensing skin and dynamic contact-avoiding behaviours, complemented with underlying inherent mechanical safety, allowing ubiquitous use of robots in shared workspaces with humans. The work builds upon state-of-the-art skin technology from TU München, world recognized path planning algorithms from CNRS-LAAS, and novel depth-perception algorithms of TU Delft.
2. Platform-independent harmonized robot software components for seamless integration with existing machinery and robots, including rapid self-calibration to operate in un-altered environments. The work builds on Fraunhofer IPA's leading role in the ROS Industrial consortium aiming at such software systems.
3. Standard core hardware modules (e.g. adaptive grippers and arms) plus a procedure to use Additive Manufacturing (3D printing) for task specific parts, brought together in a novel high-speed hardware development-and-installation procedure. The work builds upon Materialises world leading position in additive manufacturing as well as Lacquey's prominent gripping technology and Universal Robots highly popular safe and intuitive robot arms.
4. Fast teaching software for on-site robot "programming", using domain-specific models and languages (e.g., optimized for mould finishing or for snap-on assembly) so that only essential parameters and trajectories need to be taught by humans. The work builds on KU Leuven's novel iTask framework and leading open-source robotics control software.

Consortium

At the start of the project, there were State of the Art initiatives that were already targeting shorter installation periods for production lines in SMEs. For example, project partner Universal Robots already developed low cost robotic arms that can be installed in a matter of hours, that will also contribute to much faster production line installation. EU R&D project SMErobotics, claims to have developed a system that can be installed in 3 days; however this excludes the design and component customisation cycle. 'Factory-in-a-day' will build further on these developments to create the first complete hybrid robotic systems that allow for 1-day preparation and installation in a factory line, easy adaptation to changes in the production process and intuitive cooperation with humans.

The project was initiated with a consortium combining these existing initiatives with an extended set of industrial users and leading European universities and research centres on robotics. In addition to the research institutes and companies listed in the previous section (categorized per breakthrough), there were key contributions from Randstad, the world's second-largest temp agency, Fraunhofer IPT, Philips, Siemens (who unfortunately left the project early), and several smaller companies.

Vision

At the start of the project, the following visual description was made to illustrate the possible timeline of an installation day. Although the research results in Deliverable 3.1 and 3.3 later showed that the installation ultimately would need to be separated in at least two days with some allowance for production time in between, the original illustration still accurately visualizes the core concept of the project.

Vision for Factory-in-a-Day

1. A systems integrator quickly analyzes which tasks can be robotized in short-batch production work that has been done manually until now.

2. Using innovative domain-specific design templates (i.e., parameterized models of fixtures, gripper fingers, etc.) customer-specific components for the new production line are designed.

3. The parts are printed with Additive Manufacturing and mounted on highly adaptive gripper modules and on other parts of the robots.

4. The portable robots are transported to the production facility. They can be hired for short periods, together with human temp workers forming a hybrid robot-human production team.

5. The robots and auxiliary systems such as cameras are unloaded and put in place. They fully auto-calibrate in the unaltered production environment. They connect to existing machinery through a brand-independent software system with drivers for all common components.

6. The robots are taught what to do. Only minimal information is required, e.g., how to hold an object. The teacher selects a task from a domain-specific task list (i.e., only tasks relevant to mould finishing) and adjusts relevant parameters or demonstrates manipulating new objects.

7. Done! The robots do 80% of the repetitive work, humans the remaining (hard-to-automate) 20% of the work. The human co-workers have received a short training how to cooperate with the robots. The robots operate without safety fences due to
(1) intrinsic safety (low power),
(2) dynamic contact-avoiding algorithms, and
(3) intention-projection showing the robots' motion plans to human workers

4.1.3 Main S&T results/foregrounds

The content of this section is adapted from all deliverables of the project. It is organized according to the original project structure, per Workpackage and subdivided per Deliverable. All of the technical innovations come together in the Demonstration workpackage (WP7) at the end of this section.

WP 2: New business models and certification procedures

The objective of Workpackage 2, according to the Description of Work, is *to develop the business models and standards and certifications that are necessary for practical implementation of the factory-in-a-day robots. In effect, a next-generation type of robot service provider will have to emerge, a combination of a temporary work agency and a classical system integrator. This work package will provide the blueprint for such new companies.*

We completed the work by producing the five Deliverables as detailed below. In addition, a spin-off company called Delft Robotics was created to demonstrate the new concepts described in the deliverables. During the run-time of Factory-in-a-Day, Delft Robotics became a partner in the project, contributing to the deliverables in this Workpackage. The other main contributors to this Workpackage were Randstad (WP lead), TU Delft, Fraunhofer IPA, and Philips.

The work started with a detailed task and market analysis, to determine which manual tasks are suitable for automation with the next generation industrial robots (Deliverable 2.1). Next, we performed first a quick scan and then a more extensive study into human factors involved in human-robot co-production (Deliverable 2.2). Simultaneously, we developed the blueprints for new businesses which can leverage the quick-install technologies of Factory-in-a-Day in Deliverable 2.3. The two final deliverables contain theoretical recommendations (Deliverable 2.4) and the practical implementation (Deliverable 2.5) of safety standards and certifications in the context of the quick-install robots developed within Factory-in-a-Day.

Deliverable 2.1: Detailed task and market analysis

Which manual tasks could be robotized first, and which tasks were still too hard for current robot technology? Moreover, which tasks were most economically viable for robotization? To answer these questions, we developed an online *quick-scan* tool. Business owners could complete a survey, resulting in a report about the robotization feasibility of their proposed task. The analysis of the technical complexity was based on several complexity charts such as the one depicted in Figure 2.

Legend: green = immediate robotization possible orange = requires specific technical developments red = requires more long-term research	hard products with identical shapes 	flexible products (e.g. bags) 	variable shapes (biolo-gical) 	Large variable shapes (e.g. clothing) 
pre-determined position and orientation	1a	1b	1c	1d
non-touching distribution on flat belt	2a	2b	2c	2d
messy distribution (touching) on flat belt	3a	3b	3c	3d
overlapping distribution on flat belt	4a	4b	4c	4d
in a box, but in a pattern	5a	5b	5c	5d
in a messy box (bin picking)	6a	6b	6c	6d

Figure 2: complexity chart to analyse the difficulty for a robot to *pick up* objects. Deliverable 2.1 and the pertaining online *quick-scan* tool contains several of such complexity charts.

In a similar fashion, the business drivers (economic analysis) was performed to obtain a well-balanced overall indicator for robotization feasibility. In total, over 40 *quick-scan* reports were issued. The most promising cases, such as *box-filling, machine tending, polishing,* and *yucca-stem planting* have been taken as example cases for the entire Factory-in-a-Day project. The section on Workpackage 7 will contain the details of the example cases, but they will emerge throughout this report, forming the connection between the work in all of the workpackages.

Deliverable 2.2: Human Factors quick scan

This section contains not only a summary of the Human Factors quick scan that we have performed, but also a more extensive study into human-robot collaboration, which resulted in three scientific publications. The work started with the definition of four roles played by humans during the different stages of development of a Factory-in-a-Day robot system, shown in Figure 3. The focus of our human factors analysis was mostly on the role of the operator.

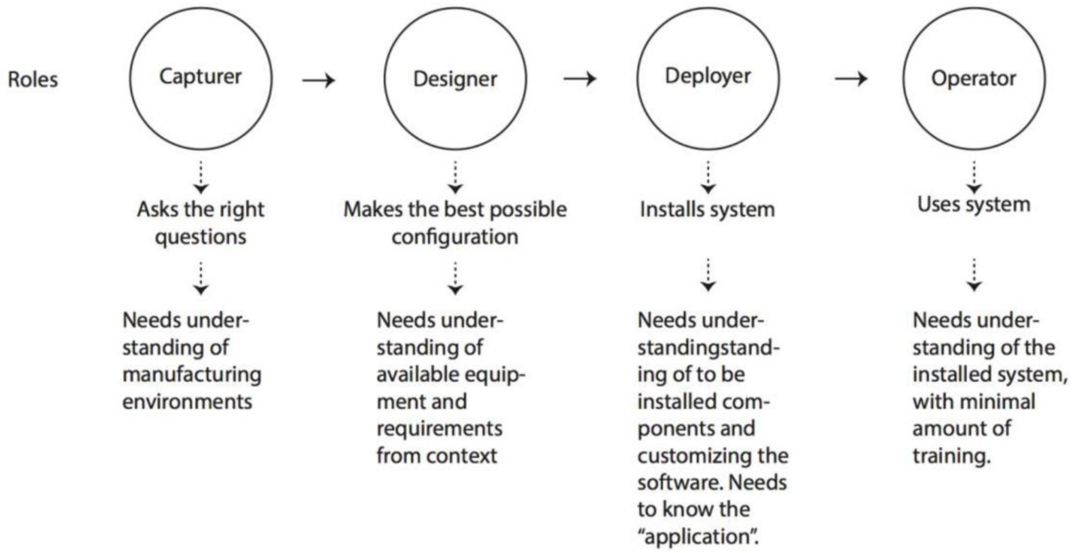


Figure 3: four human roles during the development of a robot system. The text shows which information is needed for each of the roles. In the remainder of the analysis, we focused on the role of the *operator*.

There is a large body of textbook knowledge on human factors with respect to the envisioned Factory in a Day system. This considers both physical and cognitive ergonomics. Deliverable 2.2 contains a comprehensive overview of the following topics, including a thorough literature list:

- Engineering physiology: the inclusion of physical ergonomics to assess physical workload and workplace design guidelines. This specifically applies to the operator and operator roles within the envisioned FiaD system.
- Situation awareness: "demons" and tools to improve awareness (feedback, affordances, feed forward). This requires additional attention while exploring the different responsibilities the operator might have during coproduction (Remote controller, Supervisor, Co-worker, or Teammate).
- The notions of assessing usability, which is an extension of the field of cognitive ergonomics including topics like learnability and satisfaction for the system operators.

This deliverable also contained a first overview of safety norms regarding operation and training robots and robotic systems. We briefly discussed the ISO norms 11161, 10218, 13482 and the ISO technical specification 15066. The standards and norms are discussed in more detail in the section on Deliverables 2.4 and 2.5 below.

The literature on actual human-robot co-production is rather sparse. To understand exactly when and how the human worker interacts with the collaborative robot in terms of *physical* interaction and *information exchange*, we developed experimental setups to analyze machine tending tasks[3] and to test human-robot collaborative box packaging tasks in a realistic setting[4], see Figure 4.

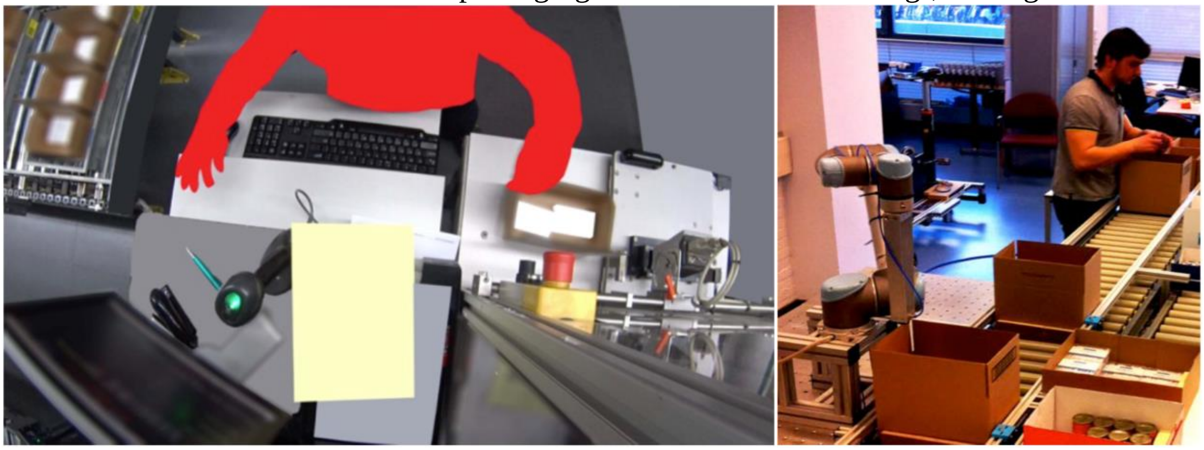


Figure 4: Left: top view of a test setup for a machine tending task, to study the physical and cognitive (information) activities of a human operator. Right: realistic test setup to analyze human-robot interaction (both physical and cognitive) during collaborative box packing.

The analyses resulted in the "Human-Machine-Product-System framework (HMPS)". The proposed framework defines explicit and fixed number of actors in the system and forces the expression of the system using these actors: Human, Product, Machine, and System. Furthermore, the types of interaction between the actors are made explicit and are clearly divided between physical transfers and transfers of information. Using this framework, we performed a review of the current state-of-the-art in collaborative human-robot co-production[5]. We concluded that there was surprisingly little actual interaction between robot and human; in most cases, the tasks were clearly divided between the human and the robot and not much interaction was reported, even though the robot and the human shared the same workspace and collaborated on the same tasks. For the remainder of the Factory-in-a-Day project (and beyond), this leads to the decision to focus not much on human-robot interaction during the *operational* phase, but to focus mostly on developing technologies to speed up the *installation* phase, while adhering to (but not developing further) the safety requirements for human-robot workspace sharing, see Deliverables 2.4 and 2.5.

Deliverable 2.3: High-level business concept and organizational structure scenarios

The goal of this deliverable was to analyse several potential business models for the quick-install robots created in Factory-in-a-Day. For the analysis, we used the Business Canvas tool as depicted in Figure 5. Three business models showed to have great potential. The first is a business model for a "normal" robot systems integrator, yet one that aims at maximizing the speed of installation. The blueprint for this business model was so promising that the spin-off company Delft Robotics (www.delftrobotics.com) was started. The second business model was called "Combined Labour/Technology/Process QuickScan (LTPQuickScan)". Our proposal is that a temp agency such as project partner Randstad collaborates with a technology provider such as Delft Robotics or project

[3] Argun Cencen, Jouke C. Verlinden, Jo Geraedts: "Qualifying the performance of human robot coproduction at a relabeling station", 11th Int. Symp. on Tools and Methods of Competitive Engineering, 9-13 May, 2016, France.
[4] Cencen, A., van Deurzen, K., Verlinden, J. C., & Geraedts, J. M. P. (2014, September). Exploring human robot coproduction. In Proceedings of the 2014 IEEE Emerging Technology and Factory Automation (ETFA) (pp. 1-4).
[5] Argun Cencen, Joule Verlinden, Jo Geraedts, Characterizing the state of the art of Human-Robot Coproduction. 7th International Conference, ICSR 2015, Paris, France, October 26-30, 2015, Proceedings, pp 135-144

partner FactoryControl. Together, they provide the customer with an integral advice on which (sub)tasks to robotize for a new factory installation. This proposal has inspired the start of the Dutch company Smart Robotics, which collaborates with a local temp agency to provide exactly such a service.

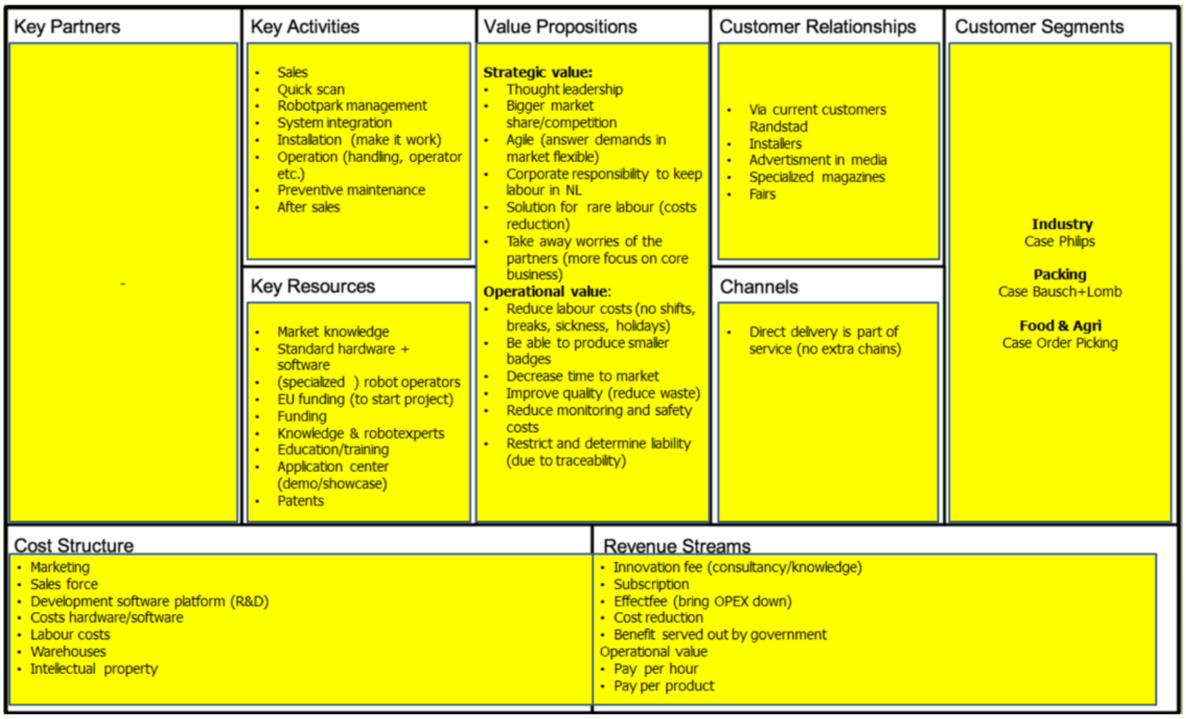


Figure 5: Business canvas for the analysis of various Factory-in-a-Day business models.

The third business model deemed promising at first, was what we called a “Human-Robot-Team Labour Service Provider”. We envisioned a joint venture providing both the robot technology and the human labor. We extensively experimented with this model, trying to create a viable case for customer Bausch and Lomb. Eventually, the results showed that the state of the Factory-in-a-Day technology was not yet sufficiently advanced. The main conclusion, drawn by partner Randstad, is that such business models will only become feasible once the robot system development and installation phases together will take less than one week. Admittedly, the state of technology is not yet ready for that. Therefore, the focus of the Factory-in-a-Day project from this point onward has taken a more technology-oriented approach to maximise progress on the technologies required for quick installation.

Deliverable 2.4: Safety standards assessment and safety training inventory

Current safety regulations and safety standards relevant for robots have not been drafted with the highly modular and reconfigurable robots of Factory-in-a-Day in mind. As a consequence the necessary procedures to achieve compliance are time-consuming and require a large amount of paperwork. In addition alteration of a robot system usually requires almost the full process to be repeated. In order to enable setting up an automation system with the time scale intended in Factory in a Day, it is essential to speed up these procedures.

This deliverable identified approaches to reduce the workload to comply with regulations and especially to speed up the deployment process by certifying parts of the automation system and preparing technical documentation application-independent in advance. These strategies can be supported by the development of software tools that can generate parts of the technical documentation as well as user manuals and training material automatically based on the components of the automation system. Additional approaches are discussed to reduce the amount of training by designing machines in a way they can be intuitively operated or by the use of experienced personnel.

The deliverable furthermore gives an outlook on the possibility to change regulations in order to simplify the way modular safety components are safety certified. One was to establish connection to an ISO standardisation committee dealing with modularity for service robots. This recommendation was followed up in the next Deliverable.

Deliverable 2.5: Novel certification structure for both robot and human labor side

Following the recommendations from Deliverable 2.4, project partner Delft Robotics has implemented novel certification procedures. Within this deliverable, we reported the results, observations, and modifications to the recommendations from a practical point of view. Also following the recommendations, several partners have contributed to the ISO standardization committees dealing with the relevant safety standards. Although the standardization processes are very slow, such that individual contributions are not identifiable, we have provided important input from the Factory-in-a-Day perspective into the development of new or updated standards, as detailed in Deliverable 2.5. In Figure 6, we list all relevant standards for Factory-in-a-Day type of robot systems.

Standard	type	Scope	Description
ISO 12100 – Safety of machinery – General principles for design – Risk assessment and risk reduction	A	Machinery	General design principles and basic requirements for the safe mechanical design of machines
IEC 60204-1 – Safety of machinery – Electrical equipment of machines – Part 1: General requirements	B	Machinery	General design principles and basic requirements for the safe electrical design of machines
ISO 13849-1 – Safety of machinery – Safety-related parts of control systems – Part 1: General principles for design	B	Control systems in machines	Definitions of performance levels (PL), defining a minimum required control system reliability
IEC 62061 – Safety of machinery – Functional safety of safety-related electrical, electronic and programmable electronic control systems	B	Control systems in machines	Definitions of safety integrity levels (SIL), defining a minimum required control system reliability
ISO 10218-1 – Robots and robotic devices – Safety requirements for industrial robots – Part 1: Robots	C	Industrial applications	Safety requirements for the design of industrial manipulators
ISO 10218-2 – Robots and robotic devices – Safety requirements for industrial robots – Part 2: Robot systems and integration	C	Industrial applications	Safety requirements for the integration of industrial robots into automation systems
ISO/TS 15066 – Robots and robotic devices – Safety requirements for industrial robots – Collaborative operation (under preparation)	–	Industrial applications	Guidance for collaborative robots including force and impact limits (publication expected end of 2015)

Figure 6: list of applicable safety standards, including ISO/TS 15066 which has been developed during the Factory-in-a-Day project with input from project partners Universal Robots, Fraunhofer IPA, and Delft Robotics.

WP 3: System hardware in a day

The objective of Workpackage 3 was to develop the hardware components and the workflow to produce customer-specific hardware components for a complete production line. The first two sections below describe the workflow results, followed by sections on hardware developments, mostly revolving around Additive Manufacturing. The workpackage was led by Materialise with significant contributions from Lacquey, TU Delft, Fraunhofer IPT, Philips, and smaller contributions from the remaining project partners. Note that part of the work in WP3 was in service of other workpackages, delivering the 3D printed components as required.

Deliverable 3.1 + 3.3: Overall factory-in-a-day workflow diagram – including Description of Additive Manufacturing workflow

Deliverable 3.1 describes the robot system installation workflow that, according to our insights, should be adopted by a new type of systems integrator for proper and quick installation of robots in SMEs. The new type of systems integrator should be software-focused, and should develop and maintain a proprietary software architecture and a surprisingly small set of hardware components to select from. This should allow them to install a robot in two site visits, each of one day duration, with some development time between the two days. The main contribution in Deliverable 3.1 is the 4-step procedure depicted in Figure 7.

Final design for installation workflow

Characteristics of a new type of system integrator that should come into existence:

- Focus on quick installation
- Service includes (advice on) financial constructions, e.g. lease/subsidy
- At all times, invest strongly in R&D:
    - Research new hardware and new software algorithms (partly at research institutes, partly at systems integrator)
    - Develop new software components that integrate seamlessly
    - Develop more Learnable Skills

1. Work of new systems integrator to be done before first visit of customer site:

- Use a QuickScan tool to quickly check the feasibility of new cases
- Select new cases as much as possible without time-consuming visits (i.e., use remote tools such as phone/video)
- Customer selection: focus on similar tasks for quick implementation

2. Work to be done during first site visit: *target duration: 1/2 day*

- Obtain full 3D measurements and I/O-specs of existing equipment,
- Determine requirements on speed & accuracy
- Select components from list (robots, camera's)
- Show preliminary simulation to customer, obtain feedback on proposed setup
- Provide advice on financing options

3. Work to be done after first site visit:

- Create offer (including refined version of the simulation and financing options)
- Wait for OK on offer
- Design, print, order parts
- Use system integrator's proprietary software architecture and components (limit the software development during integration process)
- Assemble, integrate, and test at system integrator location

4. Work to be done at second and final site visit: *target duration: 1 day*

- Install at customer location
- Teach-in with Learnable Skills app
- Install remote access components for debugging and servicing

Figure 7: installation workflow for Factory-in-a-Day robot system integration

Note that the result of Deliverable 3.3 (description of additive manufacturing workflow) is part of the overall workflow. Its main result is a decision flow chart to identify if Additive Manufacturing should be used or not, which parts of the gripper should be 3D printed, which printing technologies/materials should be used, and which IP issues should be taken into account. Please consult Deliverable 3.3 for more details on additive manufacturing, and Deliverable 3.1 for detailed explanations of each blue underlined keyword in Figure 7. Although we have not completely succeeded in following the proposed installation workflow, it is in use now as a blueprint for the operations of project partner Delft Robotics.

Deliverable 3.2: Workflow Simulation Tool

One of the most time consuming aspects of new robot system installation, is the communication with the client. Oftentimes months go by, creating a proposed system design, learning of new implicit restrictions from the client, and redesigning the system once again. To alleviate this process, Deliverable 3.2 describes the development and validation of a Workflow Simulation Tool (WST). The tool was developed and tested in close collaboration with system integrators yet offers a fast and intuitive modelling solution to reason on automation scenarios. To enable this, it entails a portable tablet that runs a visual modelling environment, entitled Visual Components, combined with a handheld 3D scanning solution. Complementary to the online files, this report encompasses a description of the tool, installation and user manual, and rudimentary background to introduce underlying concepts of modelling workflows and the selection process of the contributing technologies. Because the tool itself considers commercial hardware and software, a bill of materials is included in Deliverable 3.2. The tool is recommended for all robot system integrators. The workflow with the tool is depicted in Figure 8.

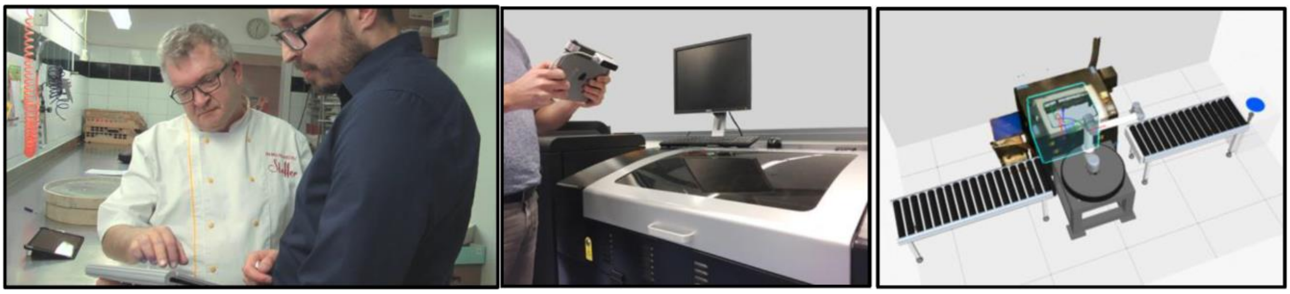


Figure 8: Use of the Workflow Simulation Tool**. Left:** the tablet-based tool allows instant interaction between client and robot systems integrator. **Middle:** the 3D scanner is used to create a computer model of the existing machinery and the shape/boundaries of the target location for the new robot setup. **Right:** the scan is imported in the 3D modeling environment which contains an extensive library of all available robot systems, tools to create conveyor belts etcetera, and a specialized Factory-in-a-Day question list to ensure all implicit assumptions and limitations are made explicit.

Deliverables 3.4 + 3.5: Library of generic 3d printable components and Design template for 3D printable gripper fingers

Deliverables 3.4 and 3.5 are focused on 3D printed parts. We use the terms “3D printing” and “Additive Manufacturing” as equal alternatives throughout the text.

Deliverable 3.4 concludes that 3D printing is only economically interesting for the production of complete grippers or parts thereof, and not for most other system components. For moving parts within the gripper, the Laser Sintering method is the only one that results in sufficiently durable solutions. The usable materials are PA 12 and TPU. There is a food-safe PA12 available and a food-safe silicone coating. TPU is not food-safe but very flexible. The motion can only be made durable with “living hinges”, i.e. hinges depending on the flexible deformation of the material and not on sliding surfaces (wear through friction). For living hinges, we have found good design guidelines to obtain a proper tradeoff between durability, flexibility, and motion range.

In Deliverable 3.5, we report extensive studies into various types of 3D printed gripper fingers. The original design was to use bellows, which we have modeled and measured, see Figure 9. This type of gripper finger has been patented, however the studies show that it is intractable to accurately model the bending behavior of such fingers, which limits the scope of applications.

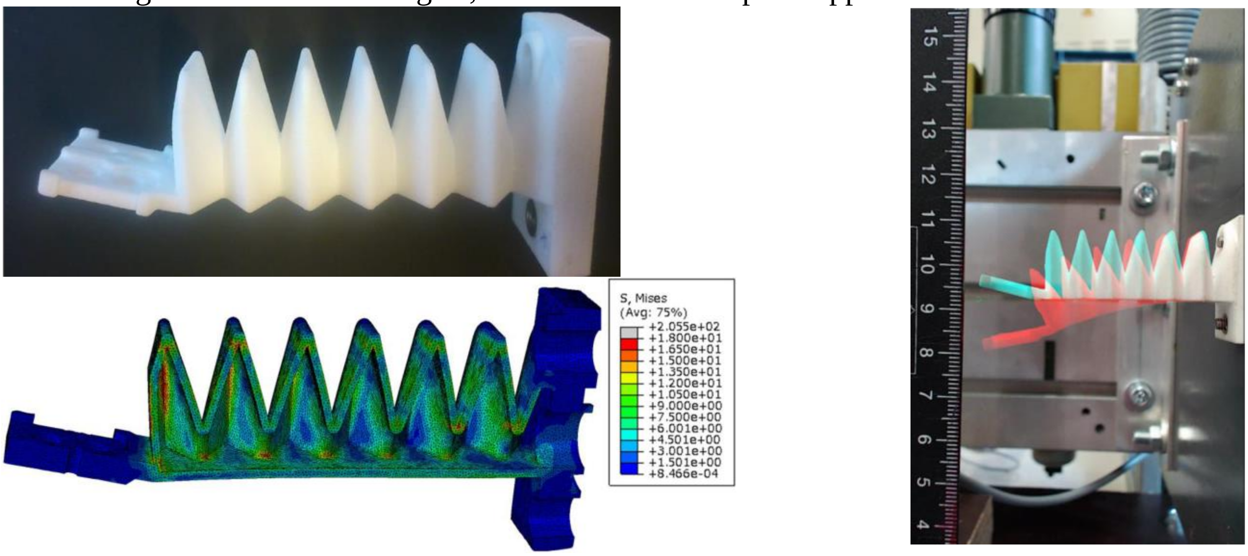


Figure 9: Bellows finger: 3D printed prototype, Finite Element Model, and test setup.

The work in Deliverable 3.5 continues with an overview on how to design grippers for 3D-printing. The main benefit of 3D printing is our concept of “printable functionality” for grippers. From hinges over valves, it can all be printed without having to make a compromise by having to select a specific, possibly suboptimal gripper. We list the gripper finger designs for the Philips cases, for various food grippers, and the (for safety) magnetically connected gripper for box filling applications. As a final example, the “Venturi Finger” was invented (patent pending[6]) showing the combination of clog-free vacuum gripping with mechanical gripping, all in a single finger, see Figure 10. Note that the original intention of this deliverable was to create standard gripper designs with modifiable parameters to address all types of applications. Our extensive experiments have taught us that such “god-type” design attempts are not successful, while a much more effective way is to create a library of *design features* to be combined quickly in a new design. The library contains for example the Venturi Finger, living hinges, standard flange designs, etc. This approach has been used successfully to create new gripper designs in less than an hour. A final noteworthy remark is that we created an extensive IP map, since there are so many patents already present in the field of gripping (with 3D printed components) that one could almost call it a “patent mine field”.

[6] U.S. Provisional Application Number: 62/516,784, Filing date: 8 June 2017
Title: Printable Venturi Valve & Robot-Fingertip with Integrated Venturi Valve for Self-Cleaning Suction Cup

Figure 10: Left: bellows finger. Middle: Gripper for Philips case. Right: design for Venturi Finger.

Deliverable 3.6: Evaluation on adaptive gripper client tests

Task 3.6 started with exploring the methods of 3D printing for adaptive grippers. Several cases were investigated, but turned out to have more simple and effective vacuum alternatives. The fresh food bin picking case required a 3D Ultra adaptive Gripper for 35% of the products. A gripper was developed within the FIAD scope (3D printed, modular, and scalable) and integrated in a test set up with user interface. Successful gripping was achieved and tested for 3 different products (Egg plant, apple, and pear). Speeds were 8 seconds/pick and can be further improved. This system could potentially replace 35% of the order pickers and reduce (human) errors.

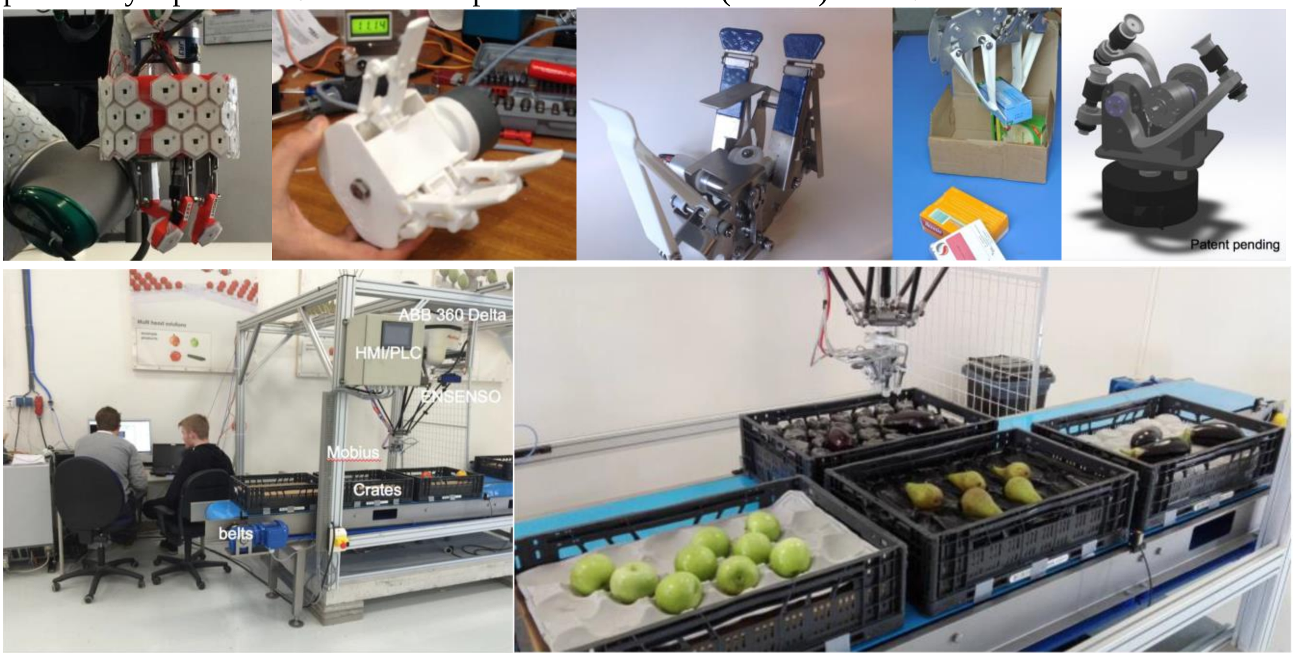
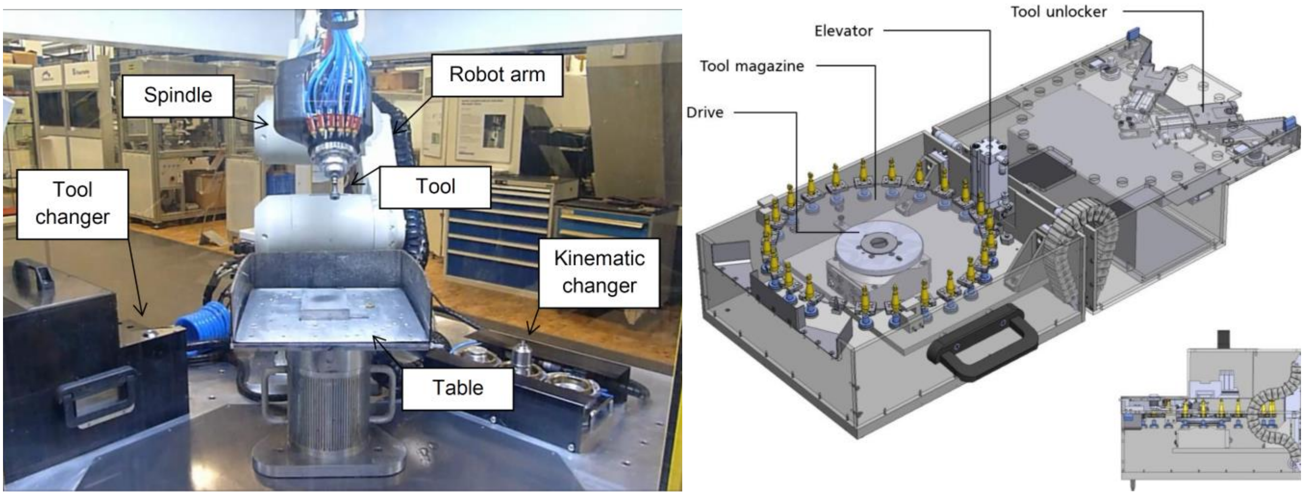
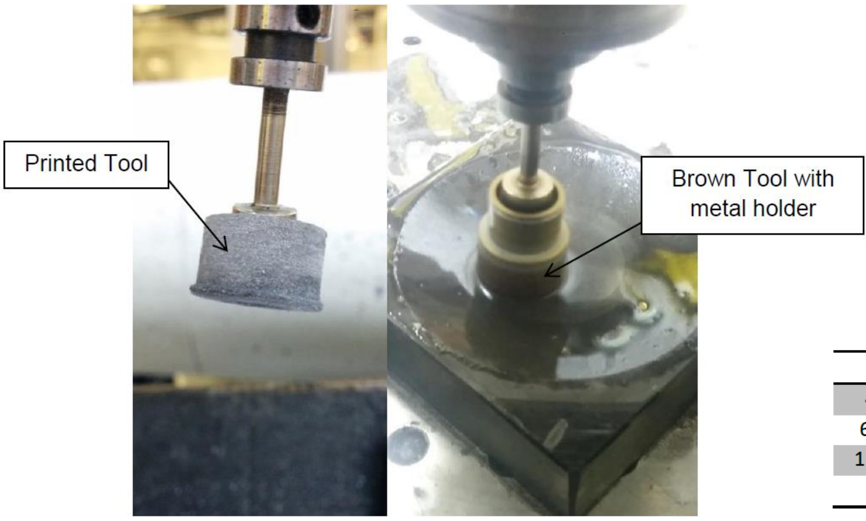


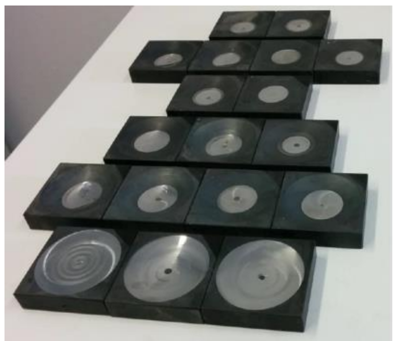
Figure 11: Top row: Evolution from ‘normal’ adaptive gripper as used in experiments by project partner TUM via fully 3D printed grippers and 3D printed gripper fingers toward a new invention for an ultra adaptive gripper, the “Mobius Gripper”. Bottom row: experimental setup for testing the gripping quality.

Deliverable 3.7: Design template for mould polishing components

Mould polishing was one of the feasible tasks as concluded in Deliverable 2.1. Nevertheless, it is a specific task which requires domain-specific knowledge, so this task was addressed separately by partner Fraunhofer IPT in Deliverable 3.7. The first discovery that was made, together with partner Materialise, was that the material ALUMIDE was perfect to 3D print the polishing tools. The next step was to dismiss the current approach of complete manual polishing, create an automated integral system (Figure 12, top row), and through extensive testing (Figure 12, bottom) determine the minimum number of tools to still obtain properly polished surfaces for any random product design. The automatization of the polishing process not only brings many advantages as repeatability and homogeneity to a process that is used to be manual, but it also brings a few main disadvantages that includes the need of a preparation using CAD/CAM software. More than that, there is also the problem regarding the geometrical limitation of the tools and the machinery used at the process. Since the focus in FiaD is to reduce the setup time on factory environment, the aim for the creation of a tool template should be defined, so that the robotic polishing preparation time could be as short as possible. Along with a template definition, the standardization of the interfaces of the hardware is also mandatory.







Probe Radii Range	Tool Radius
46,02mm -> 65,70mm	46,02 mm
65,70mm -> 114,84mm	65,70mm
114,84mm -> 458,09mm	114,84mm
458,09mm -> Infinite	458,09mm

Figure 12: Top row: integral automated polishing system. Bottom left: 3D printed tool. Bottom right: selection of test molds, and the final result of the experiments; the minimal set of tools needed.

WP 4: Dynamic obstacle avoidance

The goal of this work package was to create robot arms that are aware of all (dynamic) obstacles in their environment, and that respond by moving around these obstacles while still continuing their work. To create this awareness, not only the robot's own sensors is to be used, but also information from existing machinery is to be used, e.g. a second camera (overview) and the position sensor of axis controlled by the production line. The various sensors must be combined into one consistent model of the work environment. Current robots were safe (sometimes), but use obstacle detection only to stop moving. Here we aimed to re-plan the motion trajectory and continue working. At the same time, human co-workers will be made aware of the planned motions, such that they themselves can predict and avoid the robot as well. Additionally, we aimed to create motion plans that fulfill various task specific constraints for typical industrial applications. The automatic consideration of these constraints will drastically simplify and speed-up the deployment of a robot as part of the factory-in-a-day concept.

We have worked toward this goal through various demo setups. This includes the demo setup "TOMM" described in more detail in the videos of WP5, a PR2 mobile manipulator at the site of partner CNRS-LAAS, our final box-picking demonstrator setup and our well-known winning system for the 2016 Amazon Picking Challenge, see Figure 13. One of the main challenges in this workpackage was to integrate all of the (mostly) software technologies: the path-planning component by partner SIEMENS-PLM, the proximity-sensing skin by partner TUM, the reactive motion planner "Stack-of-Tasks" by partner CNRS-LAAS, the framework ROS with the motion library "MoveIT!" by partner TUD, and the (mostly vision) sensor data integration framework (with Deep Learning) from partner Delft Robotics. Through intensive exchange and collaboration, we are proud to have successfully coupled all of these technologies and by doing so winning (ahead of MIT, amongst others) the world renowned Amazon Picking Challenge. Finally, this workpackage has also resulted in a large number of scientific publications as listed in the Dissemination chapter of this report.

Figure 13: Our system that won the 2016 Amazon Picking Challenge

Deliverable 4.1: Prototype Robotic Skin to Partners

The main objective was to deliver a prototype of the artificial skin (Figure 14) to the partners in an early stage of the project (month 6), before the final full robot skin becomes available (month 36). This way, other partners can evaluate the skin's functionality, software integration and application in small scale before its final distribution. TUM therefore developed a hardware and software "Demo Kit" package. In extension to the raw deliverable, TUM hosted a hands-on workshop for all interested partners, in order to transfer the required knowhow to install, operate and apply the skin. The workshop has been combined with topics from the previous workshop on "learnable skills" of WP5, due to an overlap of interests and affiliations.

Figure 14: Left and middle: prototype skin distributed at month 6. Right: Fully skin-covered robot arm.

Deliverable 4.2: Website Video showing Path Planning with Proximity Sensing Data

This deliverable consisted of a first video that illustrates the ability of mobile manipulator robot executing a motion plan task with proximity sensing for reactivity, see Figure 15 (left). The robot is equipped with state of the art control task based reactive controller giving the flexibility to install in any robot platform reducing time for configurations. The proposed simple architecture exploits the hierarchical property of the controller to handle trajectory tracking tasks without compromising on safety and the final goal. The video (https://youtu.be/y-6Oyi21ioQ) shows how a robot autonomously plans a motion towards a target bottle on a table, and executes the plan robustly while evading contact measured with the (demo patch) of proximity-sensing skin.

Deliverable 4.3: Delivery of hardware and prototypes

This deliverable consisted of three components. The first was a follow-up on D4.1, i.e. the delivery of the completed robotic skin to the project partners, as shown in Figure 13 (right). This fault-tolerant low-cost robot skin by TUM, the CellulARSkin, allows to cover a complete robot manipulator, featuring around 300 cells with distance, temperature, force sensor and accelerometers. It has successfully been installed in two UR5 robot arms at TUM and TUD.
The second component was a prototype of our integrated Dynamic Obstacle Avoidance Framework developed by CNRS-LAAS in collaboration with Siemens PLM. A prototype has been released and validated with a simulation of the TOMM robotic setup from TUM, see Figure 15 (right). Finally the third component of this deliverable was our Industrial Sensor Integration Fusion Framework. A prototype of this framework has been developed by TUD using the ROS framework, and validated with the development of the Team Delft robot that won the Amazon Picking Challenge 2016 (Figure 13).

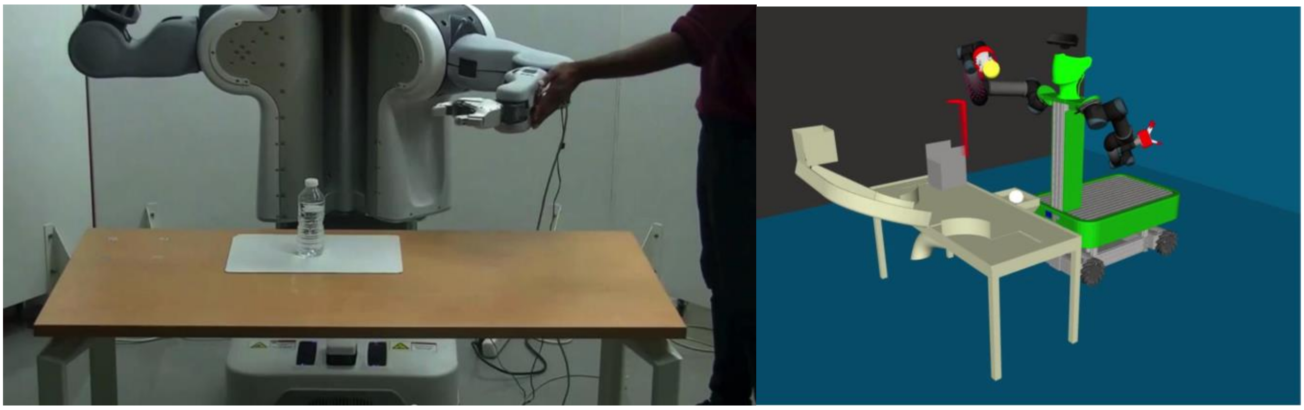


Figure 15: Left: Path planning with proximity sensing data (Deliverable 4.2). Right: simulation of TOMM setup showing our integrated Dynamic Obstacle Avoidance Framework (Deliverable 4.3)

Deliverable 4.4: Website Video Contribution: Reactive Path Planning and Motion Control

The three components of the previous deliverable (4.3) are combined into an integrated demo system which is reported here. The presented deliverable video focuses on the dynamic obstacle avoidance which is an essential component to ensure safety in the robot environment and get the robots collaborate with fellow human beings thus improving the efficiency of the processes in the factory environment which is one of the goals of the Factory-in-a-Day project.

In terms of technology, Skin Sensors from TUM, Reactive Path Planner from SIEMENS-PLM, and Reactive Controller from LAAS are combined into a manipulation scenario to illustrate the dynamical obstacle avoidance capability. The simulation video is a proof-of-concept for the future deployment in industrial robot setups. The illustration is done on the TOMM setup with skin sensors on the right forearm of the robot.

The video (https://www.youtube.com/watch?v=uLStjR7mpOI) has two parts. First, it shows the reactive dynamic obstacle avoidance behavior using the simulated skin sensors with 'Stack of Tasks'(SOT), the reactive controller driving the robot. Secondly, it contains the manipulation scenario which shows the use of the Point Cloud Library - based planner and the reactive SOT controller to avoid obstacles. The techniques shown in the video are used in the final demonstrator which is shown at the end of the project, see WP7.

Finally, Deliverable 4.4 also consisted of a video related to a slightly different topic, namely the first exploration on how Augmented Reality can be used in production planning and during deployment & operation, as shown here: https://youtu.be/uOh7mG5tmnQ. This topic will be elaborated in the next deliverable.

Figure 16: Siemens demo of industrial sensor data integration

Here, we also report the significant but incomplete contribution from former project partner Siemens AG. Although their newly acquired subsidiary SIEMENS-PLM remained an active partner, the main company Siemens AG decided to stop with Factory-in-a-Day due to severe internal reorganizations. An important contribution was their demonstration of vision sensor data integration into their robot control framework, allowing instantaneous re-positioning of objects by the robot operator. The video is shown here: https://www.youtube.com/watch?v=_6rn-dfz1Sc. Factory-in-a-Day partners have taken over the tasks of Siemens and continued the development of easy-to-use vision-guided robots.

Deliverable 4.5: Report on the effect of awareness augmentation

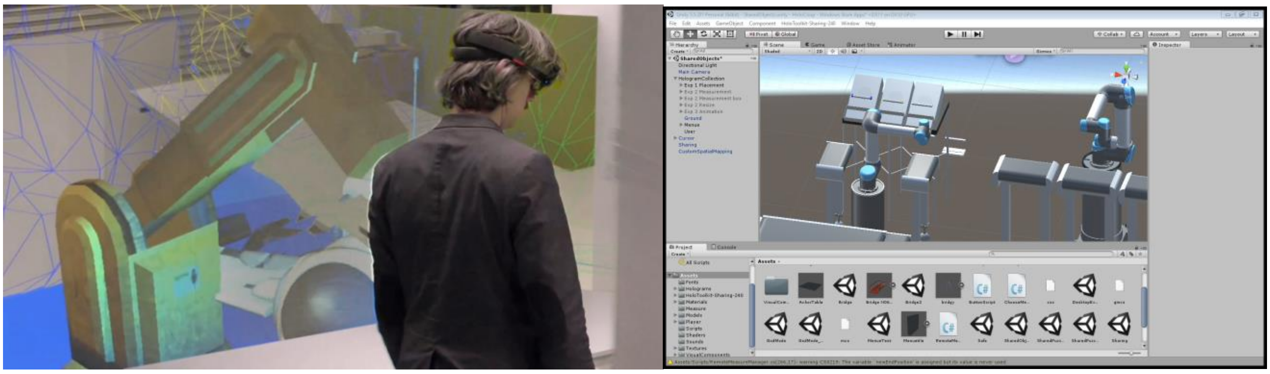


Figure 17: Head-mounted Mixed Reality display allows seamless combination of virtual and real-world objects, including real-world (current) robot positions and virtual projections of the robot’s intended motions.

This deliverable of the Factory in a Day project is concerning the development and validation of the Augmented Awareness Toolkit of human co-workers, as part of work package ‘Dynamic Obstacle Avoidance’. The toolkit was developed and tested in collaboration with system integrators, offering multiple interaction modes for use of augmented reality technology in context of knowledge exchange and decision making in manufacturing environments.

To this end, it entails the use of both traditional 2D displays and head mounted display (HMD) devices to immerse and engage the users in the augmented environment, thus placing virtual simulated content within a real, physical context. The proposed solution features collaborative as well as remote assistance capabilities, presented in three distinct interaction modes. The user experience has been tested in user studies with relevant immersion and situational awareness assessment techniques.

Complementary to the online files, this report encompasses a description of the tool, installation and user manual, and rudimentary background to introduce underlying concepts of environment augmentation and the design rationale for the contributing technologies. Because the tool itself considers commercial hardware and software, a bill of materials is included.

WP 5: Learnable skills

The objective of this work package was briefly formulated as *to make it easy and fast to teach robots how to execute a new task.*

Deliverable 5.1: Learnable skill model

Deliverable 5.1 is an extensive document which lays the fundaments for the software developments in successive deliverables. It describes the fundamental models for the specification of robot tasks. These models allow us to describe *learnable skills* in a generic way. One of the first main results was the identification of various types of stakeholders, each with their own contribution to the development of a new robot system, see Figure 18. It shows that the system developer must use or create a Domain Specific Language (DSL) within which it is easy to describe a certain type of robot task. The Application developer can use that to program the robot behavior, which in turn can be used by the Deployer to actually install the robot and set the correct parameters such as pick/place locations. The operator finally can easily monitor the system status and perform basic operations.

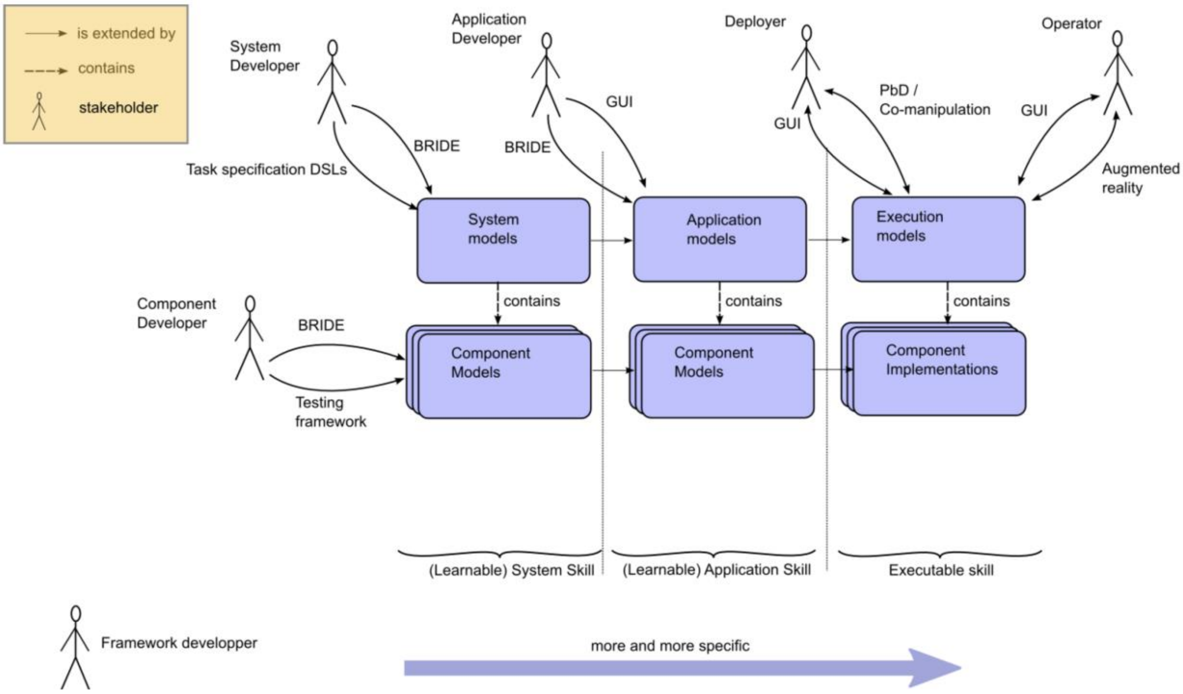


Figure 18: definition of various types of stakeholders in the process of creating a new robot system.

The deliverable describes the models, the underlying mathematics, and a proof-of principle implementation in our newly defined task specification language called *eTaSL* (for expressiongraph-based Task Specification Language)[7].

Deliverable 5.2: Update (Month 48) Learnable skill model

The work preliminary reported in D5.1 has continued throughout the project and the updated result is reported in Deliverable D5.2. New concepts were added to the eTaSL language and implementation, such as instantaneously coinciding expressions and a way to integrate sensors into eTaSL and thus extend eTaSL beyond geometric constraints. With regards to the software architecture and implementation, more detail was given on the different Orocos components involved in an application and the ROS layer that provides the application. Deliverable D5.2 also described the different approaches by which eTaSL can be extended and listed a number extensions such as extensions for the TUM skin, extensions for point cloud distance computations, extensions for the computation of distances between convex objects, and extensions to provide spline and velocity profile functionality. The resulting overall architecture provides adaptability at different levels:

- A system developer can add new functionality to eTaSL/eTC (e.g. the skin extension, using a new solver, etc.)
- The system can be configured for new Robot hardware and sensors at the Orocos level by adding new hardware driver components and configuring new connections between the components. This is independent of the actual application running at the system.
- New applications can be configured at the level of the ROS-layer.
- The applications can be deployed to new sites using the techniques of programming by demonstration (cf. deliverable D5.4).

More elaborate documentation on eTaSL is given at https://people.mech.kuleuven.be/~eaertbel/etasl.

[7] Aertbeliën, Erwin, and Joris De Schutter. "eTaSL/eTC: A constraint-based task specification language and robot controller using expression graphs." *IEEE/RSJ Int. Conf. on Intelligent Robots and Systems (2014)*

Deliverable 5.3: Website video contributions

Deliverable 5.3 was intended to show implementation progress for our work on Learnable Skills. Four videos were delivered showing various software components at work to make it easy to teach the robot how to move.

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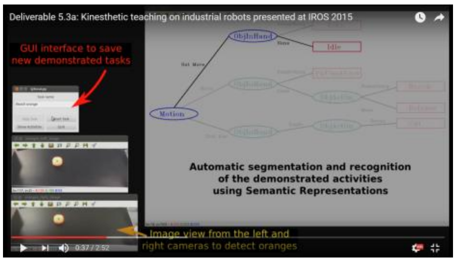
Video 1: kinesthetic teaching
www.youtube.com/watch?v=GQe4ZbNtlHo



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The goal of Task 5.2 of the FiaD project is to find techniques for natural demonstration using human-robot co-manipulation. In this regard, our semantic-based approach is able to integrate different input sensors to infer the human demonstrations in a natural manner. This process implies the integration of robot control, sensor fusion and reasoning methods as demonstrated in our video.
The novelty of our approach is the ability of automatically segment and recognize the intentions of the human that is demonstrating the task to the robot[8,9,10].
This video shows our kinesthetic teaching approach using semantic inference to allow our robot TOMM to learn the task of sorting oranges from the human in realtime.

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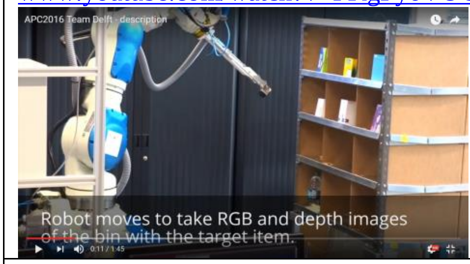
Video 2: configurable localization strategy
www.youtube.com/watch?v=PKgFy6VUC-k



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In this demonstration, the input from 2D and 3D video sensors is combined and used to recognize and localize objects on the shelves. This was demonstrated conclusively for the Amazon Picking Challenge[11]. The system was highly configurable in the sense that the shape and features of the objects were learned from training by example images. To add a new object, only the new training images needed to be added followed by an automated training process in the computer which took approximately 1 hour with our (basically standard) computing hardware.

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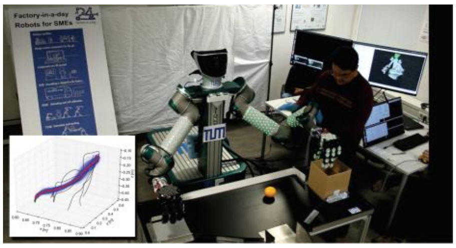
Video 3: A first learnable skill
www.youtube.com/watch?v=iv9f3hpuLY8



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This video shows the first learnable skill on the robot TOMM in an orange picking application. In combination with the learning of the intention of the human teacher as shown in Video 1, here we show that trajectory data from the reaching motion segment is used to train a statistical model of the trajectories and their variations. This is done according to the method detailed in deliverable 5.1. The advantages of this method are that it is very fast (<0.1s) and it can be applied with only a few demonstrations. This method captures also the variations of the trajectory and can thus also be combined with additional task constraints. The resulting model of the demonstrations as well as these additional task constraints are described in the eTaSL task specification language[7].

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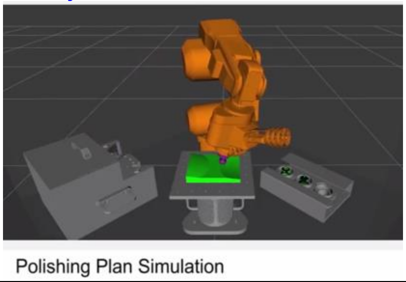
Video 4: Automated Polishing Software
www.youtube.com/watch?v=HNUn_aDWktQ



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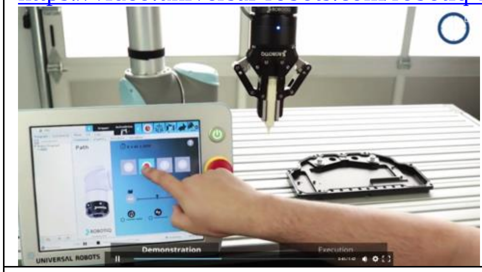
We developed a software for automating polishing, using software development platforms ROS, VTK and MySQL. In the Automated Polishing Software, the to-be polished work piece's geometry is loaded and the properties of the workpiece eg. surface finish, hardness, surface curvatures etc. are defined and analyzed. The interference system generates a polishing recipe using the existing polishing recipes in the knowledge base. Afterwards, the polishing path is checked for any collisions and the polishing plan is simulated.

</td></tr>
</table>

[8] Karinne Ramirez-Amaro, Michael Beetz, Gordon Cheng: Transferring Skills to Humanoid Robots by Extracting Semantic Representations from Observations of Human Activities. Artificial Intelligence Journal, 2015.
[9] Karinne Ramirez-Amaro , Michael Beetz and Gordon Cheng: Understanding the intention of human activities through semantic perception: observation, understanding and execution on a humanoid robot. Adv. Rob. 29 (5), 2015, 345-362.
[10] Karinne Ramirez-Amaro, Emmanuel Dean-Leon, and Gordon Cheng: Robust Semantic Representations for Inferring Human Co-manipulation Activities even with Different Demonstration Styles. 15th Int. C. on Humanoid Robots, 2015.
[11] Hernandez, Carlos, et al. "Team Delft's Robot Winner of the Amazon Picking Challenge 2016." arXiv preprint arXiv:1610.05514 (2016).

Deliverable 5.4: A model based task specification

This deliverable contains videos representing the work in Task 5.4, which was aimed at two approaches; a scientific approach continuing the work in the previous deliverables, and a direct application-oriented approach based on Factory-in-a-Day insights and existing systems of partner Universal Robots. Specifically, according to the Description of Work, UR developed "*the general principles behind an configurable assembly skill in the context of their existing robot controller and GUI. Intuitive programming of this assembly skill is a challenge. It will be investigated whether partial application of already modelled constraints/forces are a solution for this.*" We did investigate partial application of already modelled constraints/forces (i.e., the scientific approach) and decided that this was not already a solution. Therefore, the deliverable contains separate videos for the scientific approach (video 1-2) and for the application-oriented work (video 3-4).

Video 1: A model based task specification that includes programming by demonstration aspects https://www.youtube.com/watch?v=NhBbLwEzQ9I 	The video shows a robotic pick and pack application, where model-based task specification and programming by demonstration are combined in a learnable skill for online and reactive execution. Trajectories and its variations are extracted from programming by demonstration while allowing incremental learning.
Video 2: Use case shaver assembly: The full sequence. https://www.youtube.com/watch?v=JWclyFDpGIU 	The robot grasp each of 8 parts, move them to the caroussel where they are processed, put them back to the initially empty tray, and finally stacks the empty tray on top of the full tray. The movie illustrates a robot programming interface to build a sequence of motions in order to perform an industrial task, where shavers are built.
Video 3: Demonstration of Robotiq's Path Recording Software with URCapAuthor https://video.universal-robots.com/robotiq-force-torque-sensor-kit 	Easy path recording: 5 minute programming time, step-by-step instructions, plug & play without coding.
Video 4: Demonstration of the On Robot RG2 gripper URCap https://video.universal-robots.com/on-robot-universal-robotswmv 	The RG2 gripper is fully integrated with UR robots through the URCaps software platform. Due to the seamless integration between the robot & gripper the setup & programming time is reduced to 5 minutes and the programming requires no coding at all! Enabling your factory in a day!

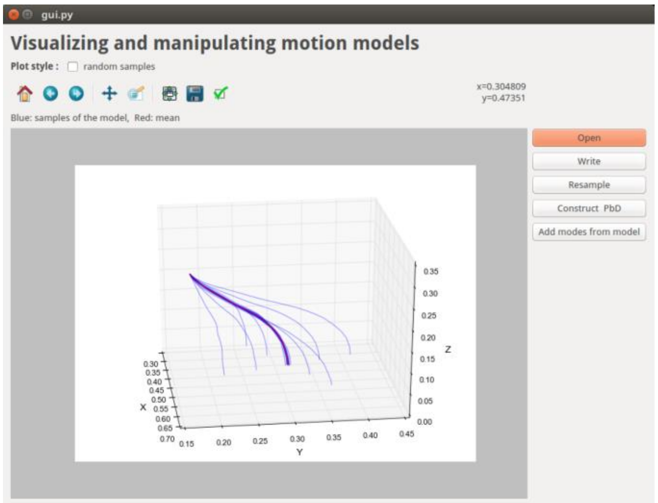
Deliverable 5.5: Description of concrete learnable skills

The ultimate result of Workpackage 5 was the implementation of examples of concrete learnable skills. The journey started with the design of a new language and then new tools (see all previous deliverables of Workpackage 5), and these have been used together with tools from other workpackages (mainly WP4 and WP6) to implement two concrete examples.

Concrete learnable skill 1: pick-and-place application

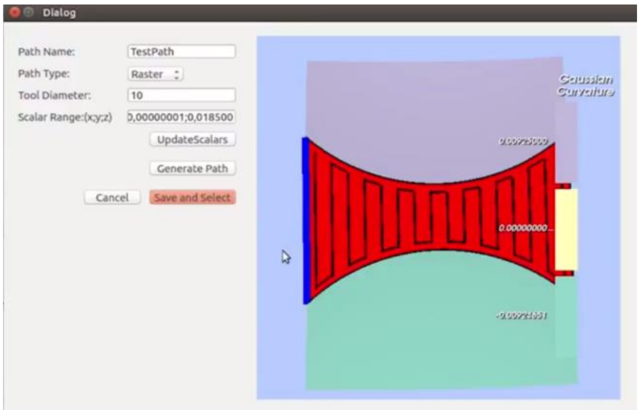
The skill of "learning to pick and place objects while avoiding collisions" is actually a combination of low-level skills which all have been implemented with the eTaSL framework and which have been combined to provide the demonstration videos reported in Deliverable 5.4. Although the low-level skills are quite different as listed below, we are very proud that they have all been implemented in a uniform way. This makes the eTaSL framework highly extensible and maintainable. The concrete low-level skills that make up the pick-and-place application are:

- Skill 1: Motion learning from demonstration (see kinesthetic teaching GUI in inset figure →)
- Skill 2: Force admittance for interaction
- Skill 3: Precise pick positioning
- Skill 4: Precise velocity tracking
- Skill 5: Limitation avoidance to stay within user-defined workspace
- Skill 6: Collision avoidance for known obstacles (using shape primitives)
- Skill 7: Collision avoidance for unknown obstacles (using point clouds)
- Skill 8: Grasping affordances for different types of objects



Concrete learnable skill 2: polishing application

For polishing applications, highly detailed CAD-models of the workpieces are generally available. The work cell typically contains a tool-changer with storage, and a specifically engineered work cell environment of which also a detailed CAD-model is available. Therefore, kinesthetic teaching as reported for the pick-and-place skill does not lead to added value for this application. However, in this application, a lot of skill knowledge is present (e.g. in selecting tools, lubricants, etc. and the order in which you apply them for a given desired result). Therefore, another approach was followed in which this skill knowledge is encapsulated in a knowledge database/expert system and accessible in a graphical user interface where the user can select the desired finishing of indicated areas of the workpiece. The implementation of the overall skill once again consists of various low-level skills which have been implemented using Factory-in-a-Day results and common technologies (such as ROS, URDF-files, SMACH, Move-It!) as were used in work package 4 and 6. A screenshot of the user-friendly GUI is shown here.



Step Creation: Path Generation

WP 6: Rapid installation software framework

The goal of this work package was to develop a complete framework for the rapid installation of a mobile manipulation system in new environments to cooperate with onsite workers. In order to focus on the acceleration of installation time the aim is to use and integrate existing software components as much as possible. The “Robot Operation System” (ROS) community that holds a huge collection of open available functionality and drivers will be the main source in this project. This workpackage has resulted in very strong results, captured partly in the new H2020 project “ROSIN: ROS-Industrial Quality-Assured Robot Software Components”.

Deliverable 6.1: Report on Quality metrics and evaluation infrastructure

A variety of service robots is available as standard platforms allowing a worldwide exchange of software for applications in the service sector or industrial environments. Open source software components enhance this sharing process, but require the maintenance of a certain level of quality. This deliverable presents an approach to an automated testing and evaluation platform which facilitates the sharing of capabilities over different robot types, environments and application cases.

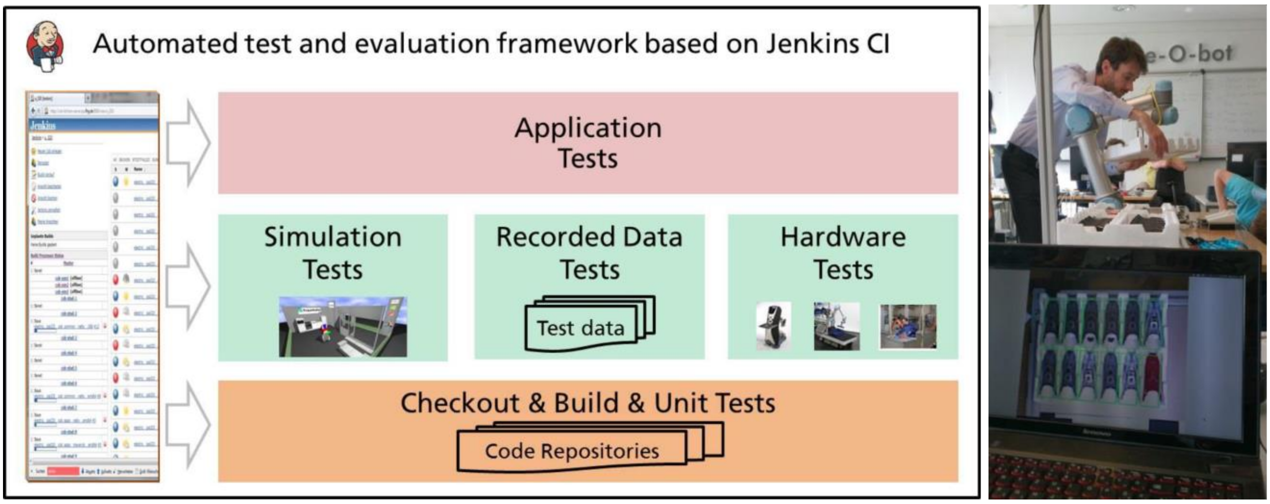


Figure 19: Schematic of automated test framework, with tests ranging from low level to application level. Right: demo Factory-in-a-Day setup which was used to validate the automated testing framework.

Deliverable 6.2: Robot Deployment Toolbox Prototype

This deliverable presents a deployment toolbox which facilitates continuous deployment in a distributed development environment. Based on the architecture shown in Figure 20, we have created a deployment toolbox which allows quick installation and combination of several robot software components here depicted as “App repository”. The toolbox is available at the repositories of partner Fraunhofer IPA, and it has been validated with two versions of the Factory-in-a-Day demo setup (the Philips case). The particular software for that setup is hosted at (https://github.com/fiad-project/fiad_hackathon_philips and https://github.com/fiad-project/bandl_robothon).

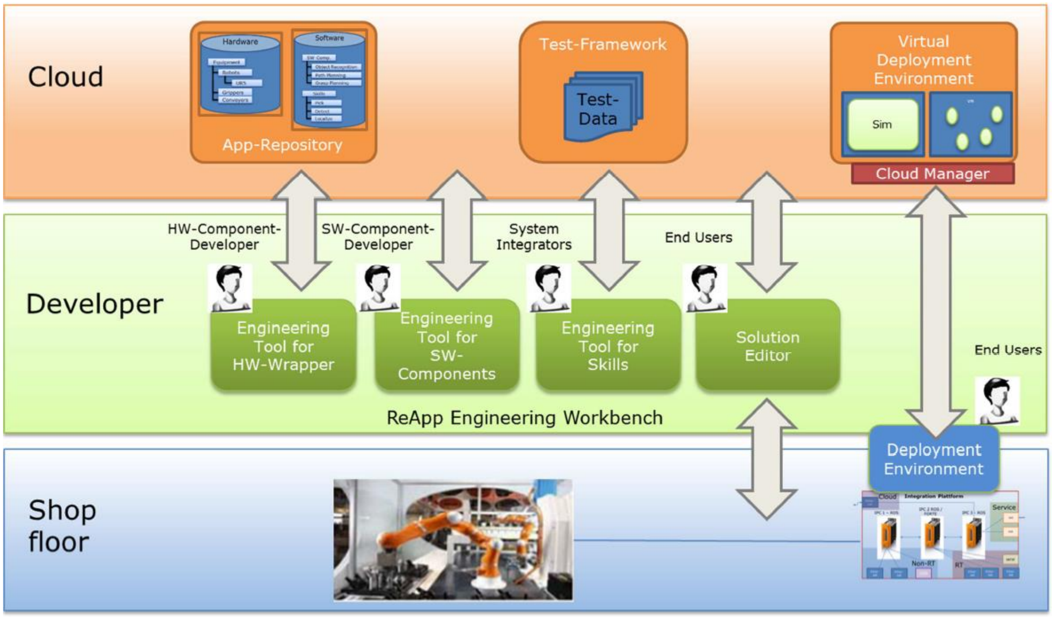


Figure 20: Robot Development Toolbox prototype, where the developer can use software components from the online App Repository and quickly configure and connect them for deployment.

Deliverable 6.3: Final Robot Deployment Toolbox And Working Robot Deployment Process

This deliverable presents the final version of the deployment toolbox which facilitates continuous deployment in a distributed development environment. With the vast amount of packages available in the open-source ROS community, it is hard for a user to select the appropriate or best one for his application. There are various approaches for solving this selection problem: Test-Driven-Development, benchmarking and continuous integration are widely adopted approaches in general software development processes, whereas in the domain of robotics, especially for distributed open source development environments like ROS, Test-Driven-Development is not widely used today.

The deployment toolbox presented in this deliverable addresses this situation by also allowing testing at integration and system levels.The test framework is available as running implementation at Fraunhofer IPA. It is running in multiple test instances at internal Fraunhofer servers which can be made available for project partners upon request. The main result is the set of deployment environment scrips available at https://github.com/ipa-mdl/ipde_utils, accompanied by three scientific contributions[12,13,14].

[12] F. Weisshardt, J. Kett, T. Freitas, a. Bubeck and A. Verl, “Enhancing software portability with a testing and evaluation platform.” In ISR/ROBOTIK, 2014.
[13] F. Weisshardt, F. Köhler, “Automatic Testing Framework for Benchmarking Aplpications” in ISR/ROBOTIK, 2016
[14] “The Automated Test Framework” [Online]. Available: https://github.com/ipa-fmw/atf. [Accessed 01 08 2016].

WP 7: Demonstration/validation

The objective of this work package was to validate the robotic systems and the business implementation procedures. This work package formed the central point of coordination of all of the tests and demonstrations that have taken place throughout the project, and as such it also served to connect all of the technical innovations.

Deliverable 7.1: Task list, evaluation metrics and test protocols

The first task within Workpackage 7 was to create a framework for evaluating cases and progress in the Factory-in-a-Day project. Since Factory-in-a-Day was the first project to focus on the *installation process,* we had to develop a framework of measures how to analyse such installation processes. The framework is comprehensively documented in Deliverable 7.1. It consists of an extensive task list of tasks and cases relevant for the project, a list of metrics to 'score' tasks and measure the progress of the project, and the test protocols outlining in general terms how to measure the metrics. Furthermore, we subdivide the metrics in Key Performance Indicators (KPI's), capturing the *goal* of the project, and PI's, capturing the *constraints* of the project. The most important KPI's for Factory-in-a-Day are listed in Figure 21 below. Throughout the project, we have reverted back to these KPI's.

KPI	Abbreviation	Phase	Definition
Cost of Installation	**CI**	Installation	This is the overall costs of installation, in EUR, or as a fraction of the total unit value.
Reuse Value	**RV**	Installation	Also referred to as 'leasability' factor. It captures the level of generic technology.
Installation Time	**IT**	Installation	This is the overall time of installation, measured in days.
Reconfiguration Cost of Installation	**RCI**	Reconfiguration	This is the overall costs of installation, in EUR, or as a fraction of the total unit value.
Reconfiguration Installation Time	**RIT**	Reconfiguration	This is the overall time of installation, measured in days.

Figure 21: Key Performance Indicators to keep score of the progress of Factory-in-a-Day and to measure individual demonstration cases.

Deliverable 7.2-7.4: Demonstration reports

To obtain an overview, we decided to combine the three Demonstration reports (Deliverable 7.2-7.4) because the each build on top of each other. The demonstration cases are shown chronologically in Figure 22. The demonstrators can be categorized in a few "dependency lines".

First, we evolved from a box-filling case (using fixed, pre-programmed positions) to a system which completely autonomously detects objects and determines how to move, ultimately leading to industrial quality results in the Philips 3 case and leading to our team winning the Amazon Picking Challenge. In the latter case, the robot was able to recognize various types of objects on cluttered shelves, and could pick and sort them as in an Amazon distribution centre, scoring better than top international teams from MIT, Mitsubishi, Bonn, etcetera.

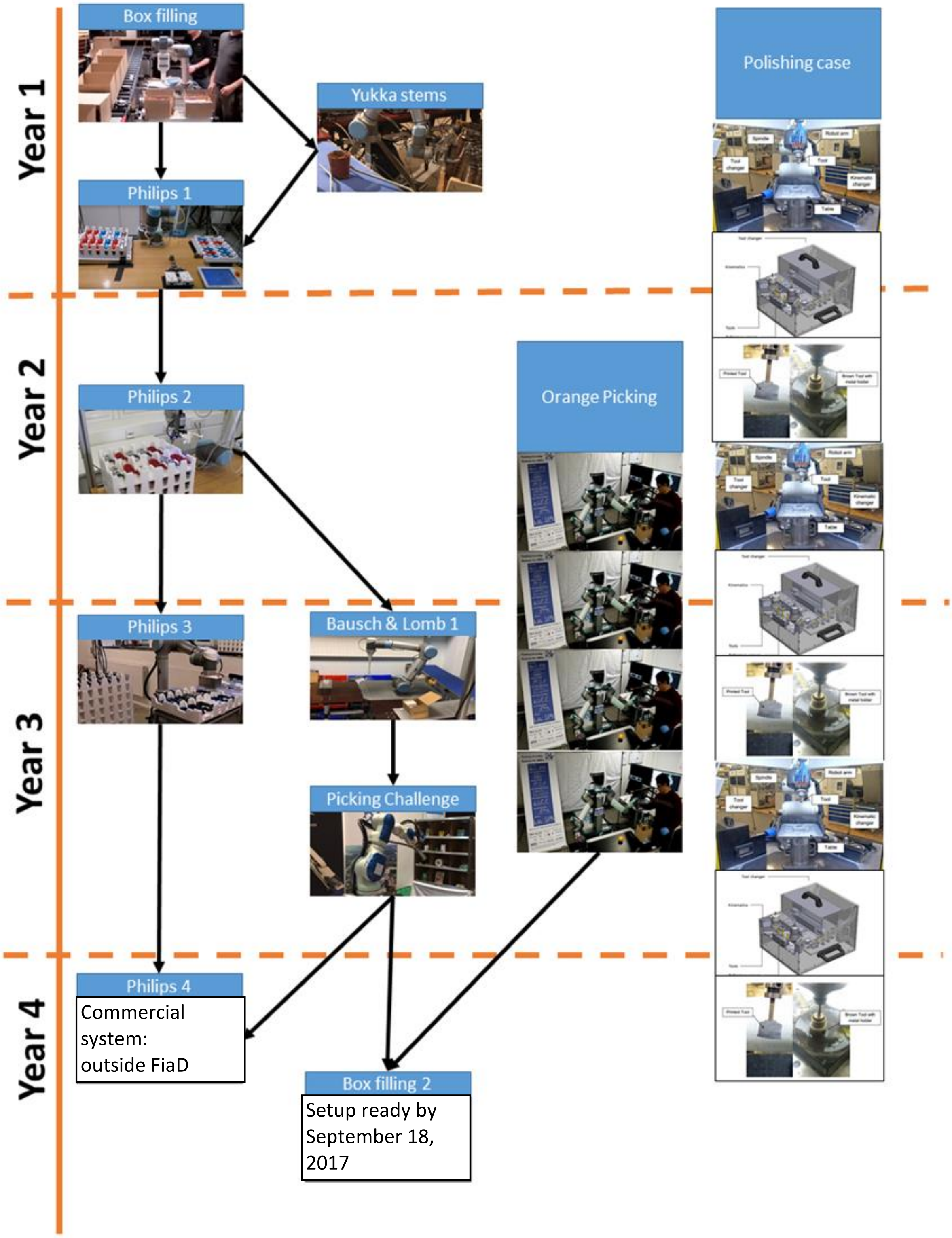


Figure 22: chronological overview of the main, interconnected Factory-in-a-Day demonstrators. Arrows indicate that experiences and technologies from cases directly influenced other cases.

Second, a more academic research setup was completed, successfully showing the combination of kinaesthetic teaching (show the robot what to do) with vision and motion planning. The proximity-sensing skin of partner TU Munich was an important component in that demonstrator, which was transferred also into the final box filling demonstration. Third, we have worked on a separate setup for the automation of mould polishing tasks, according to the Description of Work. Although the setup differs mechanically from the other setups (larger machine, more rigid placement of mould and tools), we have re-used ROS-based software and we have equally analysed the use of 3D printing for quick creation and setup of tools. Finally, separate demonstrations have been delivered by Siemens (quick-install vision-based pick-and-place actions), by CNRS-LAAS (mobile manipulator demonstrating reactive motion planning behaviour), and by Universal Robots (the now commercially available UR Caps platform, resulting from Factory-in-a-Day demo "UR+"). Videos of these demonstrators are online here: http://www.factory-in-a-day.eu/media/videos/.

An important remark is that the complexity of the robotic task was increased for each subsequent demonstrator, which had implications for the installation time. Especially for the "Philips 3" case in year 3, the installation time and effort was exceptionally high due to the fact that we wanted to break away from academic demonstrations and create industrial-quality robust performance. The four graphs in Figure 23 clearly show that the investment paid off; from the "Philips 3" case onward, we achieved 100% of the industrial robustness specs (i.e., uptime according to requirements, usually 95%).

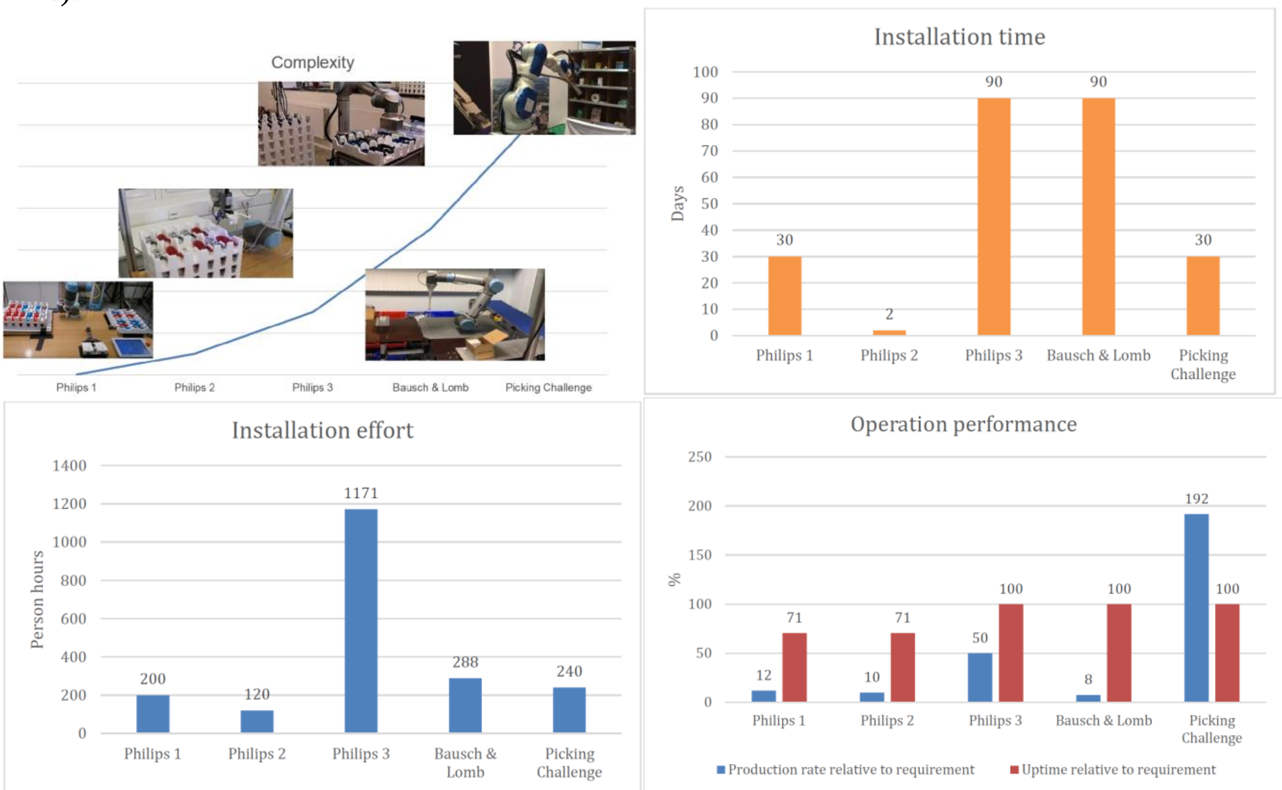


Figure 23: Overview of the complexity of the Factory-in-a-Day cases, and overview in progress in Factory-in-a-Day performance indicators. The Amazon Picking Challenge system performed much better than the requirement because the system needed only half of the allotted 15 minutes to complete the challenge. However, for actual implementation in a warehouse, a 4-fold speedup would still be required, which would require a faster image processing computer and some optimization in the code and the workflow.

The Amazon Picking Challenge demonstrator was the most visible result of Workpackage 7. The challenge 2016 included two parts: in the picking challenge a set of products from the Amazon product range needs to be picked from the shelf and placed in a tote. For the stowing challenge, it was the other way around: products are to be picked from a tote and stowed into the shelf. The robot system consisted of a 7 DoF manipulator, ROS software with MoveIT as a core component for motion planning and Deep Learning as a core algorithm for object recognition. The system completed the series of 12 item picks within 6.5 minutes, less than half of the allotted time thereby securing victory for the team.

4.1.4 The potential impact and the main dissemination and exploitation activities

The content of this section is largely based on Deliverable 8.9, and potentially overlaps with information in the tables that will (should) automatically be generated by the SESAM / Participant Portal interface for Section 4.2 of this report.

In this section, we give an overview of the main results of the Factory-in-a-day project and a draft idea on how consortium partners intend to use these project results in on-going and future activities, in their further R&D and product marketing strategies. We list in detail the exploitation activities implemented over the project's four-year period. The results provide manifold possibilities for commercial exploitation, as well as take-up in scientific projects. Therefore, this deliverable overviews all the partners' exploitation activities including: MSc/PhD thesis, teaching/training services, follow-up projects, open source software, product/service development, spinoff/start-up companies and IPR actions (e.g. patents).

To sum up, these are the highlights in terms of exploitation:

- 1 spin-off company directly from the project: Delft Robotics
- 2 patents (Materialise: Printable Venturi Valve & robot-Fingertip/ TUM: Interactive robot surface)
- 12 projects (different funding schemes) that build on results of the project
- Software components: several open-source ROS-control frameworks, also used in ROS-industrial, MoveIT, Kineo Path Planner ROS-component
- Products:
  - developed gripper placement algorithms in latest product CoreTakr
  - URCaps / UR+ has been a great success for UR and some third party hardware vendors. A number of registered active developers are working on new extensions for the UR robot platform.

Other partners are still in discussion about licensing or building spin-off companies (TUM/TU Delft), results might only be expected to be finalized after the end of the project.

Deliverable 8.8: Survey amongst SME's

Before listing all of the Factory-in-a-Day dissemination and exploitation activities, it is useful to provide insight in the motivation of SMEs for using (not) robotic technology Therefore, as reported in Deliverable 8.8 we carried out a survey entitled "Market Analysis of Plug and Work Robots for SME's"

In the deliverable, we describe the current market situation of industrial robots in Europe. Thereby, the definition of SME's, the market volume and its players are introduced. This section aims to give a rough overview about the development and market sizes in the industrial robot industry.

The number of sold robots in Germany and Europe is expected to increase. Especially within the automotive industry, where industrial robots are used the most, medium-sized and large *Small and medium-sized enterprises* (SME's) have increased their amount for new investments. Considering that personnel is one of the biggest cost blocks for those companies and traditional robots are quite expensive, new concepts such as 'Plug and Work' robots aim to reduce costs and help SME's to ensure competitiveness.

However, to tailor Plug and Work robots for SME's it is necessary to understand their needs and concerns. Therefore, an online questionnaire study in the three biggest SME industries (i.e., automotive, metal, and rubber and plastics) in Germany was conducted. The goal of the questionnaire was to figure out how SME's perceive their current situation and how they assess Plug and Work robots.

Factor	Level of Threat
Price competition	4.89
Shortage of experts	3.75
High purchase prices	3.74
Access to capital	3.28
Pace of innovation	2.98
Market regulations	2.86

Threats in the market for SME's that could lead to the decision of investing in robot technology, as perceived by the respondents of the survey.

Factor	Average Score
Large variety in the product portfolio	4.53
High acquisition and operating costs	4.13
Low production quantity	4.13
Elaborate maintenance	3.73
Lack of knowledge	3
Low flexibility of robots	2.73
Discouraging employees	1.8
Long installation time	1.73
Short live-cycles	1.73

Barriers for SME's to implement robots, as perceived by the respondents of the survey.

The results confirm our notion that SME's perceive the ongoing price competition as threat for their business. When being asked about the reasons why they are reluctant to implement robots, costs and maintenance were mentioned as barriers. In the same vein, they expect that robots are safe, flexible, and easy to program.

All of the mentioned points constitute an advantage in Plug and Work robots compared to traditional robots. Derived from our survey we found out that when promoting Plug and Work robots for SME's it is necessary to create offers which include trainings for SME's how to use them. As a medium to advertise, especially classical media such as tech magazines or fairs should be used.

Deliverable 8.9: Exploitation activities

The project's results cover a range of different exploitable assets. During the time of writing the proposal, "at least two spin-off companies are expected to arise from Factory-in-a-Day. For both companies, preliminary business plans have already been investigated", the current state of the spin-off aspect is the following:

- TUM is in ongoing discussions about licensing the skin-sensor technology and also discussing several options for the creation of a spin-off company. At the point of writing this deliverable, no decisions have been taken.
- The idea to create a company at TU Delft for renting out robots has not been followed, instead another spin-off company, Delft Robotics, has been founded in Delft (see Table 1 below)

- TU Delft is also looking into a another spin-off company with respect to the Workflow Simulation tool (see Table 1 below)

Two patents have been filed from different partners (Materialise/TUM, more details below).
Inventions and ideas from the projects can further be found in several products, for instance a machine for lettuce-handling and in the online platform UR+, an online showroom, providing you with cutting-edge products to customize a UR robot.

The industrial partners, Materialise, Philips, PAL Robotics and Siemens also used results from Factory-in-a-day for adjusting internal production processes or updating products.

In the last years, several projects have been created during the runtime of Factory-in-a-day, so that the knowledge created in our project will be further increased and also spread in different directions on a European as well as a national level. Factory-in-a-day partners participated or initiated several H2020-EU-funded projects: ROS-IN, Scalable, Robmosys, Co4Robots as well as several projects on a national level (Belgium/The Netherlands). Demonstrations and publications from these projects also contribute to a further enhancement of knowledge originally gained from Factory-in-a-day on an international level.

With respect to software developments - there are a number of open source repositories available, where the developments of Factory-in-a-day are accessible. The work of Factory-in-a-day has always been closely linked to ROS (Robot Operating System). Several partners contribute to the ROS community with different code, see the following links to the software repositories:
https://github.com/ipa-mdl/ipde_utils
https://github.com/ipa-fmw/atf
https://github.com/git-afsantos/haros
http://moveit.ros.org/
http://wiki.ros.org/ros_control
Furthermore, Siemens will update the latest Kineo Path Planning software with a ROS-component. This includes a major update on the Kineo Collision Detector (KCD) for faster and more configurable collision checks. PAL Robotics now uses Automated Test Framework and Docker as internal tools.

Below we provide two overviews of exploitable results, first as listed per workpackage (Table 1) and then listed per partner (Table 2).

Result	**IPR**	**Exploitation approach**
WP 2: Business model and orgainsational innovations developed	Owned by Randstad and TU Delft	Creation of a new business unit, as a spin-off company or joint venture between Randstad and various partners
➔ Due to lack of technological readiness, Randstad postponed the idea of a spin-off company to a later stage. The estimated scalability of the current solutions is not positive because they are only applicable in very specific situations. Coming nearer to the end of the project, it became clearer that the 'market' is not ready yet; the adoption of robots as a co-worker needs a lot of change management effort first.		
WP 3: Rapid robot hardware component integration	The specific component knowledge is owned by	Application in future R&D projects by partners MAT,

knowhow	MAT, while general lessons learned are owned by the consortium jointly and by each member separately.	LAC, FHG and TUD.
➔ Materialise filled one patent out of the Factory-in-a-day project (see Del. 8.9)		
WP4: a) Proximity sensing skin	The design knowledge is owned by the specific component producer TUM.	New designs to be patented for future commercialization trajectories. Applied into future R&D projects, specifically in the overarching RoboCom FET Flagship project.
➔ TUM has ongoing discussions on commerzialisation, one patent filled, application of skin in new pilot study with industrial partner;		
b) Dynamic Obstacle ovoidance software	The specific component knowledge is owned by the specific component owner/producer, while general lessons learned are owned by the consortium jointly and by each member separately.	Application in future research projects by LAAS and KUL. Application in industrial R&D projects by Siemens-PLM.
➔ Siemens PLM uses up-dated ROS-components to update Kineo Path planning software, including new path planning algorithms (e.g reordering for optimum spot welding trajectory)		
WP5: Learnable Skill framework	The learnable skills framework will be developed under Open Source licence. Maintained and supported for open-source community.	Applied in future development projects through component-providing partners (UR, PAL).
➔ PAL: ROS control framwork are used by ROS-industrial (http://wiki.ros.org/ros_control)/ Automated Test framework and Docker have been adopted as internal tools (https://github.com/ipa-fmw/atf)		
WP6: Reliable Software Framework	The software framework will be developed under Open Source licence.	Maintained and supported for open-source community.
➔ Open Source Software library availalbe at: https://github.com/ipa-fmw/atf (based on ROS) and https://github.com/ipa-mdl/ipde_utils		
WP7: Prototypes developed	No IPR is expected except for the copyright on the specific design, which is protected by copyright law and does not require explicit protection actions from the project to be acknowledged.	The prototype will be tested at 3-8 local events with SMEs and demonstrated at 2-3 European and/or international events (see WP8 for the full list)
→ The two main demonstrators, the Philips shaver demonstrator and the giftbot, based on an UR-5 robot arm covered with the skin (TUM) and software from various partners, were shown at public events and also on various videos. Here is a description of the demonstrators, from a technical point of view: Demonstrator Philips: One of the many steps during manufacturing a Philips shaver is tampon printing or 'tampography'. It is used to print logos, text, etc. onto parts of the shaver. The loading and		

unloading is currently done by an operator. The test case was to automate the loading and unloading of shavers into the jig of the machine. First a demo was given with fixed tray positions, in the 2nd iteration a free position of trays was used and in the final demo a full 3D can was made to trace the products in the tray. For the final demo case the products were replaced by other shaver parts. In the final case 1 layer of trays is analyzed by a 3D camera and is emptied by the Universal robot with a 3D printed gripper by handling the shaver products into a mounting jig. <u>Giftbot demonstrator (final demonstration of the project):</u> The first prototype of the Giftbot was showcased during RoboBusiness Europe 2017 delivering Lego sets to visitors. The robot picks products from a container (packaged stack), and delivers them to a human by dropping them at a specified location. The robot detects dynamic obstacles such as the human's hand using the distance sensors on the skin, which triggers a motion pause. The robot resumes motion once the obstacle is cleared. The skin provides additional human-robot interaction by i) using the LEDS to notify the status of the system, and ii) using the pressure sensors in a set of cells to receive the operator's notification to resume operation after re-filling the product container.		
WP8: Other dissemination material illustrating the full broadness of Factoryin-a-Day concepts and lessons.	Jointly owned, according to dissemination plan, also with explicit license to consortium members to use in individual communications provided that Factory-in-a-Day is mentioned as source.	This material will be used amongst others during the dissemination events planned to promote Factory-in-a-Day to the European citizens and especially the capabilities of EU industry to satisfy their needs now and in the future.
➔ Several material for dissemination were produced during the project runtime and delivered towards the partners.		

Table 1: Exploitation results per work package

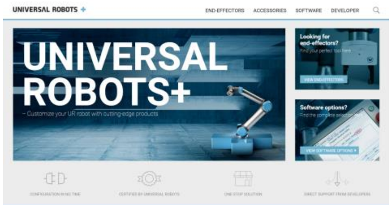
Exploitable asset	Type: Hardware, Software , service, patent, spin-off, project, …)	Partner	Description	Time frame
PhD Thesis	PhD	LAAS	Nirmal Giftsun's PhD defense "From Robustness to Resilience in Robot Control"	Planned for Dec 2017
Course on algorithmic of manipulation planning	Course	LAAS	We have developed a course on the algorithmic of manipulation planning with some practicals based on HPP software : https://github.com/humanoid-path-planner/hpp-practicals.git	2017 onwards
HPP contact with company in	Software	LAAS	Visit of Kawada Robotics (Tokyo, Japan) in October 2016, in order to discuss how the	10/2016-

Japan			manipulation planning technology that was developed in the project, can be used for robot programming. We chose Kawada because we believe they are the most advanced company in manufacturing bi-arm collaborative manipulators (robot Nextage). Following the visit, a master student worked on further developing a GUI and solving some benchmarks on Nextage (video on our YouTube Channel: https://www.youtube.com/watch?v=aUG52ryy80E)	
Flanders Make project Fast and Intuitive Robot Programming (FINROP)	National Project	KU Leuven	The project's goal is goal is to lower the barriers for Flemish manufacturing companies to employ collaborative robotic technology. Flexible Robot Solutions is planning to use eTasl in commercial applications, focused on company interaction: atlas copco, Audi factory in Vorst, Belgium, Kuka Houthalen, FRS. Project website: http://www.flandersmake.be/en/projects/fast-and-intuitive-robot-programming-finrop	1/11/2016 to 1/11/2018
Echord++ 3DSSC	EU-Project	KU Leuven	3DSSC focuses on an application in the food industry, applications in other industries will benefit from the results of this experiment. Application is currently under further development by FRS – a Belgium company that uses eTaSL as core technology. Project website: http://echord.eu/3dssc/	2016
Flanders Make, project YVES:	National Project	KU Leuven	Project aims to tackle three research challenges: • Studying the impact of human-robot interaction in a manufacturing cell on human operators and on safety systems • Developing improved control algorithms and intuitive robot teaching methods • Developing design rules for HRCW and real-time scheduling algorithms to coordinate robot and human actions. The partner's focus is on programming for demonstration in industrial applications. The applications are currently under definition,	from 2017 until 12/2020

			one of the applications will be with Audi (in Vorst, Belgium) on mounting batteries in electrical vehicles. Project website: http://www.flandersmake.be/en/projects/augmented-workers-using-smart-robots-manufacturing-cell-yves	
Robmosys	EU Project	KU Leuven & PAL	Robmosys (H2020 project) envisions an integrated approach to robotic platforms by applying model-driven methods and tools on existing technologies for an open and sustainable European robotics software ecosystem. Project Website: http://robmosys.eu/	1.1.2017-31.12. 2020
Research project	National Project	Rand-stad	project with TNO on logistics and robotics	
ROSIN project	EU Project	TU Delft & Fraun-hofer IPA	The goal of the project is making ROS-Industrial better and even more business-friendly and accessible. Project Website: http://rosin-project.eu/	1.1.2017 – 31.12.2020
MoveIT open-source international community	software	TU Delft	MoveIt! is state of the art software for mobile manipulation, incorporating the latest advances in motion planning, manipulation, 3D perception, kinematics, control and navigation. It provides an easy-to-use platform for developing advanced robotics applications, evaluating new robot designs and building integrated robotics products for industrial, commercial, R&D and other domains. MoveIt! is the most widely used open-source software for manipulation. http://moveit.ros.org/	
Delft Robotics	company	Delft Robotics	Spin-off company of the project founded in 2015, a software company that integrates robots in production processes. http://www.delftrobotics.com/	2015-
	Infra-	TU Delft	A meeting place for SMEs in order to test	Started in

RoboHouse	structure		new technologies, founded by Festo, Den Haag University, TNO, Delft University of Technology and Innovation Quarter.	2017
Kineo Path Planner ROS-component	Software	Siemens PLM Software	The current ROS-component will be updated to latest Kineo Path Planning software, including a major update on the Kineo Collision Detector (KCD) for faster and more configurable collision check. It will also include some new path planning algorithms and some new features used in industry, like point reordering for optimum spot welding trajectory. http://www.plm.automation.siemens.com/en/products/open/kineo/collision-detector/index.shtml	2017-2019
Innovation Cluster Drachten (ICD)	Project	Philips	Innovatiecluster Drachten (ICD) is an internationally active ecosystem of 15 collaborating high-tech companies and knowledge institutes operating at the forefront of innovation and competitive on the global market. PROJECT "Connected Colloborative Robots" Project Website: https://www.icdrachten.nl/	2014 -
Region of Smart Factories (North Netherlands) (ROSF)	National Project	Philips	Development of a self-learning visual quality check-learning of visual 3D. Project Website: http://rosf.nl/partners/	
Adaption of production process	technology	Philips	A UR robot arm is now set-up in the production process using 3D camera, a technique that we learned from the project.	2016-
Interview	video	Philips	Video interview with Prof. Jan Post about the results of the project for Philips and follow-up (available on YouTube)	2017
Patent on fingertip	patent	Materialise	U.S. Provisional Application Number: 62/516,784 Filing date: 8 June 2017 Title: Printable Venturi Valve & Robot-Fingertip with Integrated Venturi Valve for Self-Cleaning Suction Cup	2017
New research projects → design automation	Project	Materialise	The basic starting point is: "Reduce the design time". One way of doing this is by reusing existing designs. Therefore, when designing, take into account future change in requirements and incorporate them already in the design through for example	2016-

			parameterization. Company will use lessons-learnt.	
Printable functionality catalogue		Materialise	New approach to the design: It was identified as Object-Oriented geometrical design. The idea is quite simple: just like in OO-programming, do not try to automate or capture every possible design in an overcomplicated system. Instead work with comprehensive design patterns. Within the project, the patterns focused obviously on gripper functionality.	2017
IP-map for grippers	Patent analysis	Materialise	IP map was made: – 50 patents were analyzed – 6 relevant ones are mapped – One patent filled later	2014-
Gripper questionnaire	Process	Materialise	The goal is to come to a workflow to derive a gripper concept and design starting from the description of the automation task. This implies that the automation task should be described completely. To come up with a (gripping) solution, we need some questions answered, which were put in a questionnaire. (see Del. 3.3). The questionnaire is used in the company for analysis purposes.	2014-
Workflow Simulation Tool	Software, spin-off	TU Delft	The Workflow Simulation Toll is communication tool that facilitates discussing about the practical (geometrical and other) issues of an automation cell between the different stakeholders (experts as well as non-experts) Under further development for integration into commercial suites. Open 3D scan repository to open in late 2017.	2017 until end of 2018
Möbius gripper	product	Lacquey	We have shown the proof of concept of the Möbius gripper for an order picking fresh food application. Since our merger with FTNON in 2015 we stopped selling grippers. We did use our developed gripper placement algorithms in our latest product the CoreTakr (www.Coretakr.com). That application is now being sold in Europe.	2017

				
URCaps / UR+	Online platform/product	UR	The URCaps / UR+ has been a great success for us and some 3rd party hardware vendors (like Robotiq). We now have a number of registered active developers working on new extensions for our robot platform. https://www.universal-robots.com/plus/ 	June 2016
Ongoing Discussion with potential licensees for skin cells	License	TUM	Currently, we are following different discussion with potential licensees for producing the robotic skin cells	2017
Pilot study	Project	TUM	We are currently working in a pilot study with industrial robotic company on use of the robotic skin on one of their robots (software)	205-2017
Discussion on spin-off company for skin cells	Potential spin-off	TUM	There has been an approach to create a spin-off company during the project runtime, but this did not work out, therefore, we are currently looking into different other options.	ongoing
Patent	patent	TUM	A first patent on one of the sensors has already been filled before the start of the project (EP12172602.0) Filled 25.9.2015	2015
Co4Robots	EU project	PAL	The goal is to build a systematic methodology to accomplish complex specifications given to a team of potentially heterogeneous robots; control schemes appropriate for the mobility and manipulation capabilities of the considered robots; perceptual capabilities that enable robots to localize themselves and estimate the state of the dynamic environment; and their systematic integration approach.	1.1.2017-31.12.2019

			Project Website: http://www.co4robots.eu/	
ros_control framework	software	PAL	ROS-control framework developed within FiaD project have been used also by ROS-Industrial: wiki.ros.org/ros_control	
Automated Test Framework and Docker	software	PAL	Automated Test Framework and Docker have been adopted as internal tools in PAL Robotics: github.com/ipa-fmw/atf	
ScalABLE 4.0 project	EU project	Fraunhofer IPA	The development and demonstration of an open scalable production system framework (OSPS) that enables optimization and maintenance of production lines 'on the fly', trough visualization and virtualization of the line itself. The project outcomes focus not only on line monitorization, but also on its control and construction in real time. Project Website: www.scalable40.eu/	01/2017-06/ 2020
Automated Testing Framework	software	Fraunhofer IPA	The ATF is a testing framework written for ROS which supports executing integration and system tests, running benchmarks and monitor the code behaviour over time. https://github.com/ipa-fmw/atf	2016-
ROS-I demo cell used for dissemination during lab visits	demonstration	Fraunhofer IPA	ROS-I demonstration cell used for dissemination during lab visits was installed at IPA.	09/2017 onwards
Deployment system for ROS-based robot solutions	Software	Fraunhofer IPA	Docker-based deployment system for ROS-based robot solutions. https://github.com/ipa-mdl/ipde_utils	2016-

Table 2: Exploitable assets per partner