Příloha č.1 ke Smlouvě o partnerství:

Annex No. 1 to the Agreement on Partnership:

FEASIBILITY STUDY

for a project submitted as part of Operational Programme Research, Development and Education
Priority Axis 1, Investment Priority 1, Specific Objective 2

Call: "Long-term Intersectoral Cooperation"

Cluster 4.0

Methodology of System Integration

EVROPSKÁ UNIE
Evropské strukturální a investiční fondy
Operační program Výzkum, vývoj a vzdělávání

MINISTERSTVO ŠKOLSTVÍ, MLÁDEŽE A TĚLOVÝCHOVY

Table of Contents:

1. General information

Item	
Project title	Cluster 4.0 – Methodology of System Integration
Name of applicant	Czech Technical University in Prague
Number of partners, research organisations	1
Number of partners, business corporations, state-owned enterprises	2
Reference to published financial statements for business corporations and state-owned enterprises (see Rules for applicants and beneficiaries – specific section, *Relevant for all partners of this type)*	www.justice.cz
Name of the applicant's constituent part(s) submitting the project application (name of faculty, university institute)	Czech Institute of Informatics, Robotics, and Cybernetics, CTU in Prague (CIIRC CTU)
The project's main field/group of fields as defined in the Specific rules for the Call.[1]	1AB9.1 – 1AB9.4 – Industry: Electrical engineering and robotics 1AB9.4 Use of computers, robotics and its application
The project's secondary field(s) as defined in the Specific rules for the Call.	-

[1] *Indicate both the number and the name as specified in the Rules for applicants and beneficiaries – specific section.*

2. BRIEF PROJECT DESCRIPTION - ABSTRACT

The Project opens a brand-new quality of the research and innovation collaboration across the variety of sectors. The general precondition of the successful intersectoral collaboration is the strong ***Network Of Trust*****, which can be therefore established.**

The aim of the project *"Cluster 4.0 – Methodology of System Integration"* (hereinafter also referred to as the *"Cluster 4.0"*) is the **establishment and development of the intersectoral cooperation**, based on the mutual understanding and interests between innovative companies, global industrial stakeholders and academia oriented to technical areas. The collaboration with industrial companies on research projects enables not only realisation of research tasks using real data and progressive production technologies. Moreover, manufacturing companies put pressure on necessary efficiency in research, based on high demands on short-time flexible production cycles. **The consortium of the Cluster 4.0 project** and its members from the **leading research institutes** - CIIRC CTU at the Czech side, DFKI at the German side, and **innovative industrial companies,** Sidat and CertiCon, bring together **with the support of the transnational corporations** – Airbus Group, Škoda Auto and Simens, and with a direct **link to** a dynamically developing **National Center of Industry 4.0** the new quality for the development of intersectoral cooperation in the area of Industry 4.0.

The strategic involvement of the **German research organization DFKI**, which, as well as German companies, is at the forefront of the digital transformation of the European economy and Industry 4.0, is the key aspect of the project in this respect. Thanks to this project, the Czech Republic can also draw from the positive experiences of partners and avoid errors at both the micro and macro level. The international partner, experienced with memberships in clusters and other initiatives, will provide assistance in fundraising, esp. in receiving of grants in highly competitive EU schemes (H2020). In addition, the project develops other aspects of cooperation, such as joint laboratories, combined advanced educational activities and transparent dissemination policies and activities.

Project also develops its own strategic agenda to enhance positive, sustainable and effective cooperation between partners and uniquely link the different interfaces of existing technology (IoT) platforms and clouds. The research of the project is **one of the most challenging topics in Industry 4.0**, which is the issue of **system integration and the creation of a unified and flexible software architecture for adaptable manufacturing systems** using a service oriented paradigm - the Cluster 4.0 Integration Platform (C4IP).

3. Profile of the Applicant and Partners

The Consortium of the ***Cluster 4.0 – Methodology of System Integration*** Project consists of following subjects:

Cluster 4.0

Academic Partners

Industrial Partners

Supporters

3.1. Brief Characteristics of the Project Applicant

3.1.1. Profile

The project applicant is the **Czech Technical University in Prague** (CTU), a public university-type higher education institution[2] that ranks among the largest and oldest technical universities in Europe. CTU currently has eight faculties (Faculty of Civil Engineering, Faculty of Mechanical Engineering, Faculty of Electrical Engineering, Faculty of Nuclear Sciences and Physical Engineering, Faculty of Architecture, Faculty of Transportation Sciences, Faculty of Biomedical Engineering and Faculty of Information Technology) and more than 1 800 scientists and academic staff[3]. It is actively involved in research and scientific activities. CTU offers 119 degree programmes and its master's and doctoral programmes have produced more than 16 200 graduates since 2009. CTU educates modern professionals, scientists and managers who are proficient in foreign languages as well as dynamic, flexible and able to quickly adapt to market requirements.

CTU actively participates in collaborations with industrial partners, business and research institutions, public administration and government; it cooperates with more than 700 institutions from 84 countries from all over the world. At the same time, it already has initial experience with both spin-off activities (e.g. CertiCon, Neovision, Polyx, Protys etc.) and with forming start-ups (e.g. Cognitive Security, Agentfly Technologies or Workswell).

Since 2011, more than 14 000 technical papers have been published, of which 6 500 were original publications in prestigious journals[4]. According to the QS World University Rankings, CTU is at the top in computer science and electrical engineering (51th to 100th place) and is internationally competitive.

CTU's main long-term strategy in developing R&D consists in supporting and developing successful research centres for basic and applied research, improving the environment for research activities and supporting and developing the activities of research teams.[5]

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[2] *Legal form of the entity: VVS – Public or state university (Act No 111/1998 Sb., on universities and amending and supplementing some other acts (Act on Universities)). Type of organisation according to the Framework: RO – Research organisation. Tax identification number: CZ68407700; ID no.: 68407700. Address of registered offices: Zikova 1903/4, 16636 Prague 6, Czech Republic. Telephone: +420 22435 1111. Rector: doc. RNDr. Vojtěch Petráček, CSc., http://www.cvut.cz. Constituent part concerned: University institute – Czech Institute of Informatics, Robotics and Cybernetics (CIIRC CTU)*

[3] *2011–2016 CTU annual reports, https://www.cvut.cz/vyrocni-zpravy-o-cinnosti*

[4] *Scopus, publications 2011–2017, affiliation: Czech Technical University, 30 October 2017, www.scopus.com/home.url*

[5] *CTU Strategy, Objectives of research and development processes, https://www.cvut.cz/strategicke-materialy*

Applicant – constituent part concerned	Czech Institute of Informatics, Robotics, and Cybernetics CTU in Prague
Registered office	Zikova 1903/4 166 36 Prague 6 – Dejvice Czech Republic
Office	Jugoslávských partyzánů 1580/3 160 00 Prague 6 – Dejvice Czech Republic
Website	www.ciirc.cvut.cz
Establishment of the company	2013
Number of employees	177

In terms of project management and implementation, the constituent part concerned is the **Czech Institute of Informatics, Robotics and Cybernetics (CIIRC CTU)**, and collaboration with other parts of CTU is envisaged. CIIRC CTU is a university institute established through a decision of the CTU Academic Senate dated 24 April 2013 pursuant to Section 34 of Act No 111/1998 Sb., as of 1 July 2013.[6]. The main objective of CIIRC CTU is to promote the integration of informatics and cybernetics research and education at CTU, building both on links with centres that have been built outside Prague within Research and Development for Innovation and on strong links with international research centres and the private sector. Since its inception, CIIRC CTU has been growing consistently and it aims to hire up to 350 employees, especially researchers and doctoral students.

In 2014, a decision of the Ministry of Education, Youth and Sports supported the creation of new infrastructure and, in 2017, a new building opened within the CTU campus in Prague-Dejvice. CIIRC CTU became the centre of support for the ideas of the Industry 4.0 national strategy, which was developed by a team of experts headed by prof. Mařík, Director of CIIRC CTU, in 2016 and which became the basis for the establishment of the National centre for Industry 4.0. CIIRC CTU is one of the founders of this centre, which brings together academic and research institutions with industrial companies and professional organisations, and aims to help introduce the principles of Industry 4.0 in the Czech Republic. Within this centre, the Czech Republic's first Testbed 4.0 is gradually being built and developed, which is mainly used for the development and transfer of technologies and solutions for Czech small and medium-sized companies.

[6] CTU CIIRC pursues the following basic objectives: 1) Integrating and internationalising science and research in progressive areas of informatics, robotics and cybernetics and related fields; 2) Providing modern education for doctoral students with the participation of prominent experts; 3) Setting up joint scientific and research teams and laboratories with leading universities and other organisations; 4) Creating an interconnected physical space within CTU in order to accelerate innovation and knowledge transfer into practice

CIIRC CTU demonstrated its viability and excellence by winning three successful projects in 2017 within the 'Support for excellent research teams' call under the Operational Programme Research, Development and Education, thus obtaining more than CZK 450 million. Two of these projects are led by ERC grant holders (Dr. Urban – ERC Consolidator, Dr. Šivic – ERC Starting) and the strategic partners of these projects are prestigious foreign institutions (TU Delft, INRIA and Radboud University Nijmegen).

In 2016, another important partnership was established through signing an agreement with DFKI, a leading German research institute in the field of innovative software technologies. Together with other partners (BUT-CEITEC and ZeMA) this partnership played an important role in the RICAIP project, which was supported in the first round of the 'Teaming' call under the H2020 programme and whose objectives include the development of the Czech-German research centre for Industry 4.0, joint research and education, innovation management and technology transfer. As part of this project, the Testbed for Industry 4.0 becomes one of four geographically distributed centres in the Czech Republic that are virtually interconnected. In addition to academic institutions, CIIRC CTU also cooperates with industrial enterprises, either through the enterprises' involvement in the testbed or through joint laboratories e.g. with Škoda Auto a.s., EEIC.

3.1.2. Main Areas of Research and Development

CIIRC CTU constitutes an effective platform that integrates science, education and technology transfer in progressive technical fields and brings together excellent teams not only from CTU but also from across the Czech Republic. CIIRC CTU has a wide range of professional interests, including automatic control and optimisation, robotics, artificial intelligence, computer graphics, computer vision and machine learning, designing software systems and computer devices, designing decision support and diagnostic systems and using these systems in medical applications, distributed decision support systems, industrial diagnostics, telematics, and designing user-friendly and beneficial solutions for citizens and residents (including smart homes, smart cities).

The main research programmes include the following, which also make up the basic research organisational structure:

- Cyber-physical Systems (CYPHY)
- Intelligent Systems (INTSYS)
- Industrial Informatics (IID)
- Robotics and Machine Perception (RMP)
- Industrial Production and Automation (IPA)
- Cognitive Systems and Neurosciences (COGSYS)
- Biomedical Engineering and Assistive Technology (BEAT)

Other research groups – shared platforms support horizontal cooperation between different teams within CIIRC CTU and between CTU and external partners, thus making it possible to respond flexibly to new possibilities for cooperation. These shared platforms currently include:

- Centre for Applied Cybernetics (CAC)
- AI&Reasoning
- IMPACT (Intelligent Machine Perception)

- Testbed
- Industry 4.0 (Robotics for Industry 4.0)

CIIRC CTU staff have long-term experience with building cooperative platforms and linking teams from various disciplines. The national cooperative platform model has been successfully developed and implemented over the 12-year existence of the Centre for Applied Cybernetics (CAC), which is now an organisational part of CIIRC CTU. CAC was created as a research group combining CTU teams with other technical universities in the field of artificial intelligence, machine perception, automated control and automation resources.

In all research programmes, all types of research (basic, applied, contract) are developed. Key research capacity in terms of personal and knowledge synergies and cross-sectional research field can be also defined as follows:

- **Artificial Intelligence** – artificial intelligence methods are present in the research of several research programmes at CIIRC. INTSYS focuses on applying AI methods in order to add intelligent behaviour to software systems and machines. Research into AI&Reasoning deals with devising suitable Automated Reasoning and Machine Learning methods that learn reasoning knowledge and steer the reasoning processes at various levels of granularity. Combining them into autonomous self-improving AI systems that interleave deduction and learning in positive feedback loops.
- **Machine Perception** - the research field is focusing on fundamental and applied research in computer vision, machine learning and robotics to develop machines that learn to perceive, reason, navigate and interact with complex dynamic environments. However, the aspect of machine perception is also investigated within industrial informatics and the development of fast optimisation algorithms that are flexible while guaranteeing reliability and performance.
- **Machine Learning** - Effective and safe machine learning algorithms are an important precondition for autonomy in robotics, which has been recognized as a strategic bottleneck for smart industrial applications. Reliable sensing and perception methods for mobile industrial robots constitute the precondition for the use of robots in the Industry 4.0 applications. Additional challenges are present when it comes to the combination of perception and dexterity.
- **Control Systems** – This research area focuses on the efficient use of computational, communication, manufacturing and human resources, and it places high demands on communication networks, security and real-time operating systems.
- **System Theory** - Research in this area addresses linear systems, optimal control, robust control, theory of systems with transport delay, applied control theory, numerical methods of mathematical modelling, modelling and control of systems with distributed parameters, control theory.
- **Mobile Robotics -** This research field is focused on design and development of intelligent mobile robots - self-guided vehicles. The overall goal is to develop a highly robust cognitive control system for this kind of robots and to bring novel ideas into particular solutions. For central tasks are considered: sensing of the environment, sensor data processing and data understanding, all leading towards automated world model building and/or updating. The used knowledge representations of the world are designed and optimized for planning of robot activities and for

self-navigation in real (indoor) environments. As such system requires highly complex control and decision-making the crucial parts is always the sensing and sensor data understanding.

- **Mechatronics and Manufacturing** – The research field is focused on machine tools and automated production. Special topics include dynamic properties of machine tools, process-machine interaction, machining technology and mechatronic devices for automated production. New machine tool concepts are created and new design methods are developed.

3.1.3. Quality of Research Activities To-Date

TOP Research Results

CIIRC CTU's best results include publications in periodicals with the highest IF, prestigious grants, applications and internationally successful patents:

ERC Consolidator Grant	**Artificial Intelligence for Large-Scale Computer-Assisted Reasoning** **Principal Investigator: Josef Urban**
Funding authority	ERC Consolidator Grant no. 649043 (from 2015/09 to 2020/08), financed by the European Commission (ERC) within the H2020 programme
Short description	Within the project, automated reasoning and machine learning methods are developed which learn reasoning skills from large formal corpora and lead automated reasoning processes at different structural levels. At present, it appears to be extremely difficult and barely feasible to create an explicitly-programmed solution to the task of an effective automatic proof of the grand theory theorem. Instead of trying to manually create every detail of the reasoning algorithms for all verification areas, we create algorithms that extract large amounts of reasoning knowledge through learning from large formal corpora, leveraging the acquired advanced knowledge to effectively guide the reasoning process, and themselves improving the algorithms by using feedback loops between learning and deductive exploration.
Website	http://ai4reason.org/
Role in project	Coordinator, scientific lead

Output	**Creating own school of discrete automatic control** **Authors: Vladimír Kučera, Michael Šebek**
Short description	The result is the Youla-Kučera parameterisation of all regulators that stabilise the given system. It is used in standard synthesis tasks that require reference signal monitoring, fault suppression, specific placement of system poles, achievement of final pulse response, optimisation of H2 or l1 standards for selected signals, robust stabilisation, or robust placement of system poles. In addition, non-standard applications of Youla-Kučera parameterisation are also used, such as system stabilisation with limited input amplitude, reduction of system response overshoot, and design of stabilising regulators of a given order. The result has opened up a whole new area of research with applications in the design of optimal and robust control circuits.

Publication	**Energy Efficient Scheduling for Cluster-Tree Wireless Sensor Networks With Time-Bounded Data Flows: Application to IEEE 802.15.4/ZigBee** **Authors: Zdeněk Hanzálek, Petr Jurčík**
Journal	IEEE Transactions on Industrial Informatics

Number of citations	58/79 (WOS/Scopus)
Impact factor	6.764
Short description	Cluster planning and collision avoidance – these are the basic problems of large cluster wireless sensor networks. The goal is to meet all time limits within the entire chain of the defined set of time-bound data flows while minimising node energy consumption. By using a planning tool, system engineers can efficiently configure all necessary network parameters. This work in the field of wireless networks was further extended to include the setting-up of parameters in IEEE 802.11p, which is used in communication between vehicles that was contracted by Volkswagen in Wolfsburg in the form of an implementation in the Linux operating system.
Website	http://ieeexplore.ieee.org/document/5475355/

Publication	**Profinet IO IRT Message Scheduling With Temporal Constraints** **Authors: Zdeněk Hanzálek, Pavel Burget, Přemysl Sucha**
Journal	IEEE Transactions on Industrial Informatics
Number of citations	30/39 (WOS/Scopus)
Impact factor	6.764
Short description	The article presents an algorithm that makes it possible to create a static schedule for Profinet IO IRT communication, which is an industrial Ethernet protocol standardised in IEC61158. Furthermore, the problem is extended to include useful temporal constraints that provide additional flexibility for each message. Due to this flexibility, it is possible to retransmit synchronisation messages without holdup in the switch, or to add new messages into the original schedule.
Website	http://ieeexplore.ieee.org/document/5499439/

Pilot application	**A scheduling system to reduce A 350 aircraft fuselage assembly at Airbus by 10.2%** **Scientific director of the project: Vladimír Mařík**
Implemented within the project:	ARUM (Adaptive Production Management), project FP7 2012-NMP-ICT-FoF-314056, financed by the European Commission, September 2012 – August 2015
Short description	The project aimed to improve the process of planning and controlling the production of complex products produced in small lot sizes, typically aircraft or boats. The project budget totalled EUR 11.6 million and it was largely financed by the European Union (EUR 8.5 million). In addition to Czech institutions, 14 other partners from seven EU countries and Russia participated in the project. These also included target customers such as Airbus or EADS.
Website	http://cordis.europa.eu/project/rcn/104761_en.html

Patent	System and Method for Planning/Replanning Collision Free Flight Plans in Real or Accelerated Time Authors: Šišlák, D.; Pěchouček, M.; Volf, P.; Mařík, V.; Losiewicz, P
Identification	US 8538673 B2
Date of award	17/09/2013
Short description	A system and method for planning/replanning collision free flight plans in real-time (or accelerated-time) including planning individual flight plans for each flying asset, executing (or simulating) the planned individual flight plans, detecting violations of safety zones of each of the flying assets by negotiation and by other assets monitoring (radar sensing), and repairing the individual flight plans by real-time replanning.

Finding / Publication	Solving a problem of linear systems theory – decoupling Authors: Vladimír Kučera
Short description	Professor Vladimír Kučera has solved the long-standing open problem of linear systems theory – decoupling in a system with many inputs and outputs using static state feedback. The earliest known study of this problem dates back to 1934, and now, for the first time, a solution to this highly complex task is being presented without any restrictive assumptions about the system and the state feedback being sought. The existence of a solution depends on the existence of three lists of integers conditioned solely by system invariants with respect to the permissible transformations. The solvability conditions are necessary and sufficient. The proof of necessity is existential, whereas the proof of sufficiency is constructive and leads to the algorithm for calculating the state feedback being sought. The result will be published as an article in the December 2017 issue of the prestigious journal IEEE Transactions on Automatic Control (IF 4.270).

Patent	Systems and methods that integrate radio frequency identification (RFID) technology with agent-based control systems Authors: Vrba, P.; Macurek, F.; Mařík, V.; Hall, H.K.; Tichý, P.
Identification	8384544
Date of award	26/02/2013
Short description	The subject invention relates to systems and methods that distribute electronic data, such as Electronic Product Code (EPC) data, obtained from RFID tags by Radio Frequency Identification (RFID) readers and/or servers to agents within an agent-based control system. The systems and methods employ a component that collects, filters, processes, and stores electronic product data. The component collects electronic product data through corresponding reader and/or server interfaces. This data can be filtered to accept particular electronic product data, processed to a format suitable to the agents, and stored. Such storage can include delineating the electronic product data across rows of a table by electronic product code and across columns of the table by various types of data. Upon receiving a subscription and/or request from an agent for electronic product data, the component can obtain and convey the information to the agent.

Patent	Ontology-based system and method for industrial control Authors: Vrba, P.; Hall, H.K.; Kadera, P.; Mařík, V.; Obitko, M.; Radakovic, M.
Identification	US 20100138017 A1
Date of award	27/03/2012
Short description	An industrial control system and method of controlling an industrial process are disclosed herein. In at least one embodiment, the control system includes an order system configured to receive an order from an external source and process the order to generate an order instance in accordance with an order ontology, at least one database storing a plurality of selectable generalized production plans and information identifying capabilities of a plurality of control entities, and a product agent in at least indirect communication with the order system, the at least one database and the control entities. The product agent receives at least one portion of the order instance, selects at least one of the generalized production plans, and communicates with the control entities so as to determine a production plan instance suitable for governing at least one aspect of an industrial process in order to satisfy at least one portion of the received order corresponding to the at least one portion of the order instance.

Competence Centre	Centre for Applied Cybernetics (CAC) Established: 2000
Short description	CAC serves as a national platform for cooperation (partners include Brno University of Technology, University of West Bohemia in Plzeň, Technical University of Ostrava and others). The tasks being addressed require a highly intersectoral approach (e.g. Modelling and control of electric power generation, distribution and conversion, Intelligent man-machine interaction, Machine perception and image analysis for industrial applications, Optimisation tools for industrial informatics). The centre pools national research potential in applied cybernetics comprising the best teams from leading universities and innovative companies. Financed by Ministry of Education, Youth and Sports / Technology Agency of the Czech Republic 2000–2004; 2005–2011; 2012–2019.
Top results	• Digital modular servo amplifier with function interpreter (software, prototype), 2015 • Prototype of an interactive voice system (pilot operation), 2015 • Production optimisation system (software), 2015 • Embedded robotic system for autonomous supervision (prototype, functional sample), 2015
Website	http://cak.CIIRC CTU.cvut.cz/cs/

Publication	A Review of Agent and Service-Oriented Concepts Applied to Intelligent Energy Systems Industrial Informatics Authors: Vrba, P.; Mařík, V.; Siano, P.; Leitão, P.; Zhabelova, G.; Vyatkin, V.; Strasser, T.
Journal	IEEE Transactions on Industrial Informatics

Number of citations	45/56 (WOS/Scopus)
Impact factor	6.764
Short description	The intention of this paper is to provide an overview of using agent and service-oriented technologies in intelligent energy systems. It focuses mainly on ongoing research and development activities related to smart grids. Key challenges as a result of the massive deployment of distributed energy resources are discussed, such as aggregation, supply-demand balancing, electricity markets, as well as fault handling and diagnostics. Concepts and technologies like multiagent systems or service-oriented architectures are able to deal with future requirements supporting a flexible, intelligent, and active power grid management. This work monitors major achievements in the field and provides a brief overview of large-scale smart grid projects using agent and service-oriented principles. In addition, future trends in the digitalization of power grids are discussed covering the deployment of resource constrained devices and appropriate communication protocols. The employment of ontologies ensuring semantic interoperability as well as the improvement of security issues related to smart grids is also discussed.
Website	http://ieeexplore.ieee.org.ezproxy.muni.cz/document/6819815/?reload=true

Publication	**A Review of Architectures and Concepts for Intelligence in Future Electric Energy Systems** **Authors: Strasser, T.; Andrén, F.; Kathan, J.; Cecati, C.; Buccella, C.; Siano, P.; Leitao, P.; Zhabelova, G. et al.**
Journal	IEEE Transactions on Industrial Informatics
Number of citations	66/80 (WOS/Scopus)
Impact factor	6.764
Short description	Renewable energy sources are one key enabler to decrease greenhouse gas emissions and to cope with the anthropogenic climate change. Their intermittent behaviour and limited storage capabilities present a new challenge to power system operators to maintain power quality and reliability. Additional technical complexity arises from the large number of small distributed generation units and their allocation within the power system. Market liberalization and changing regulatory framework lead to additional organizational complexity. As a result, the design and operation of the future electric energy system have to be redefined. Sophisticated information and communication architectures, automation concepts, and control approaches are necessary in order to manage the higher complexity of so-called smart grids. This paper provides an overview of the state of the art and recent developments enabling higher intelligence infuture smart grids. The integration of renewable sources and storage systems into the power grids is analysed. Energy management and demand response methods and important automation paradigms and domain standards are also reviewed.
Website	http://ieeexplore.ieee.org.ezproxy.muni.cz/document/6915899/?arnumber=6915899

Publication	Motion tracking and gait feature estimation for recognising Parkinson's disease using MS Kinect Authors: Tupa, O.; Procházka, A.; Vyšata, O.; Schatz, M.; Mareš, J.; Valis, M.; Mařík, V.
Journal	BIOMEDICAL ENGINEERING ONLINE
Number of citations	8/17 (WOS/Scopus)
Impact factor	1.683
Short description	The main objective of this work involves the recognition of selected gait disorders in both the clinical and everyday settings. The results obtained include an evaluation of leg lengths, with a mean difference of 0.004 m in the complete set of 51 individuals studied, and of the gait features of patients with Parkinson's disease (SL: 0.38 m, GV: 0.61 m/s) and an age-matched reference set (SL: 0.54 m, GV: 0.81 m/s). Combining both features allowed for the use of neural networks to classify and evaluate the selectivity, specificity, and accuracy. The achieved accuracy was 97.2 %, which suggests the potential use of MS Kinect image and depth sensors for these applications.
Website	https://biomedical-engineering-online.biomedcentral.com/articles/10.1186/s12938-015-0092-7

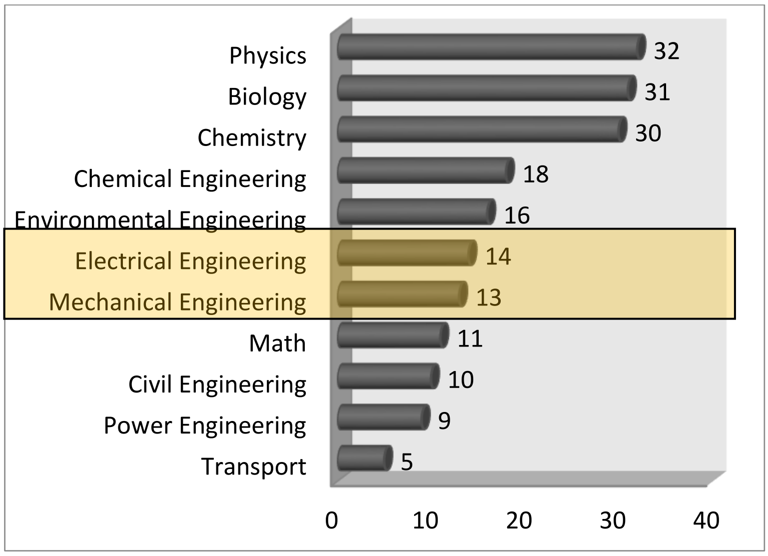
Publication	Use of the Image and Depth Sensors of the Microsoft Kinect for the Detection of Gait Disorders Authors: Procházka, A.; Vyšata, O.; Vališ, M.; Ťupa, O.; Schätz, M.; Mařík, V.
Journal	NEURAL COMPUTING & APPLICATIONS
Number of citations	10/11 (WOS/Scopus)
Impact factor	2.505
Short description	This paper presents a novel method of gait recognition that uses the image and depth sensors of the Microsoft (MS) Kinect to track the skeleton of a moving body and allows for simple human-machine interaction. While video sequences acquired by complex camera systems enable very precise data analyses and motion detection, much simpler technical devices can be used to analyse video frames with sufficient accuracy in many cases. The experimental part of this paper is devoted to gait data acquisition from 18 individuals with Parkinson's disease and 18 healthy age-matched controls via the proposed MS Kinect graphical user interface. The methods designed for video frame data processing include the selection of gait segments and data filtering for the estimation of chosen gait characteristics. The proposed computational algorithms for the processing of the matrices acquired by the image and depth sensors were then used for spatial modelling of the moving bodies and the estimation of selected gait features. Normalized mean stride lengths were evaluated for the individuals with Parkinson's disease and those in the control group and were determined to be 0.38 and 0.53 m, respectively. These mean stride lengths were then used as features for classification. The achieved accuracy was > 90 %, which suggests the potential of the use of the image and depth sensors of the MS Kinect for these applications. Further potential increases in classification accuracy via additional biosensors and body features are also discussed.
Website	https://link.springer.com/article/10.1007/s00521-015-1827-x

TOP 10 Researchers (ranked by H-index)

In order to compare the quality of researchers, the H-index indicator was used, which is based on the citation rate of the given researcher's publications. In Czarnecki, L. et al[7], a comparison of the median H-index for "full professors" showed that the median for senior researchers in fields that are relevant to the project (Electrical Engineering, Mechanical Engineering according to WOS) did not exceed 15. The median H-index for the top 10 CIIRC CTU researchers is 14.5, so the median value achieved by CIIRC CTU staff is on par with the European and global standard.

H-indices of individual workers are listed in the overview below.

Chart 1 Median H-index for "Full Professors"



prof. Dr. Ing. Robert Babuška	Position: Head of "Industry 4.0" Research group Senior Researcher, PI – "Robotics for Industry 4.0" Project
Research focus	Adaptive and learning control, nonlinear identification and state-estimation, dynamic multi-agent systems, predictive control, neural networks, fuzzy systems, machine learning. Applications: robotics, mechatronics, aerospace, process control.
Top results	• ABOUHEAF, M.I., LEWIS, F.L., VAMVOUDAKIS, K.G., HAESAERT, S., BABUŠKA, R. Multi-agent discrete-time graphical games and reinforcement learning solutions. Automatica. 2014, 50(12), 3038–3053. IF 3.020 • NAJAFI, E., BABUSKA, R., LOPES, G.A.D., Learning sequential composition control. IEEE Transactions on Cybernetics. 2016, 46(11), 2559-2569. IF 7.384
H-index	27

[7] *Czarnecki, L., Kaźmierkowski, M. P., Rogalski, A.: Doing Hirsh proud; Shaping H-index in Engineering Sciences Bulletin of the Polish Academy of Sciences: Technical Sciences. Volume 61, Issue 1.*

prof. Ing. Vladimír Kučera, DrSc., dr. h. c.	Position: Head of Department of Research Management of Platforms (PLAT) / Head of "Centre for applied cybernetics" (CAC) Research group)
Research focus	Automation and control, linear systems. Conditions for the existence of specific solutions to a Riccati equation; parameterisation of all regulators that stabilise a given linear system (internationally known as Youla-Kučera parameterisation); a synthesis method for linear control circuits based on solving polynomial equations; design of robust control circuits.
Top results	• KUČERA, V. Diagonal decoupling of linear systems by static-state feedback. IEEE Transactions on Automatic Control. Published to IEEE Xplore® May 31 2017, DOI 10.1109/TAC.2017.2710098. To appear in printed form in December 2017. (IF 2016 4.270) • KUČERA, V. From differential to algebraic Riccati equations: The influence of Kalman. IEEE Control Systems Magazine. 2017, 37(2), 153-156. IF 5.196
H-index	24
Dr. Ing. Josef Šivic	Position: : Head of the „IMPACT“ Senior researcher and Principal investigator - “Intelligent Machine Perception ” Project“
Research focus	Computer vision - a branch of computer science and engineering that aims to extract information from images. Developing learnable image representations for automatic visual recognition.
Top results	• TORII, A., ŠIVIC, J., OKUTOMI, M., PAJDLA, T. Visual Place Recognition with Repetitive Structures. IEEE Transactions on Pattern Analysis and Machine Intelligence. 2015. IF 6.077 • SEGUIN, G., ALAHARI, K., SIVIC, J., LAPTEV, Dr. Šivic. POSE, J. Estimation and Segmentation of Multiple People in Stereoscopic Movies. IEEE Transactions on Pattern Analysis and Machine Intelligence. 2015. IF 5.781
H-index	21
prof. Ing. Vladimír Mařík, DrSc., dr. h. c.	Position: Director of CIIRC CTU / Head of Department of Intelligent Systems (INTSYS)
Research focus	Prof. Mařík’s main professional interests include distributed AI, multi-agent systems, knowledge based systems, machine learning, planning and scheduling for manufacturing, etc. He is author or co-author of 6 monographs, 8 textbooks, more than 110 papers at international conferences, 30 papers in reviewed journals, and co-editor of 13 books. He acted as a co-ordinator or a local co-ordinator of several international research projects in the field of AI (EUREKA, FP6, FP7). He acted as a lead of the EU Centre of Excellence MIRACLE in 2000-2006. He was the General Chair of the DEXA'13, Co-chair of HoloMAS’11, HoloMAS’13, HoloMAS’15, Program Chair of IEEE SMC 2013 Conference, etc. Prof. Mařík acts as the VP of the IEEE SMC since 2014 and the Chair of the Scientific Board of the Technology Agency of the Czech Republic since 2010.

Top results	• Strasser, T. - Andrén, F. - Kathan, J. - Cecati, C. - Buccella, C. - et al.: A Review of Architectures and Concepts for Intelligence in Future Electric Energy Systems. IEEE Transactions on Industrial Electronics. 2014, vol. PP, no. 99, art. no. 1, ISSN 0278-0046., (IF 2014 8,785) • Vrba, P. - Mařík, V. - Siano, P. - Leitão, P. - Zhabelova, G. - et al.: A Review of Agent and Service-Oriented Concepts Applied to Intelligent Energy Systems. Industrial Informatics, IEEE Transactions on. 2014, vol. 10, no. 3, p. 1890-1903. ISSN 1551-3203.(IF 2014 8,785)
H-index	16
doc. Ing. Tomáš Pajdla, Ph.D.	Position: Department of Robotics and Machine Perception (PMR) / Head of "Applied Algebra and Geometry" (AAG) Research Group
Research focus	Computer Vision, Robotics and Machine Learning, Geometry, Algebra, Optimization
Top results	• ARANDJELOVIC, R., GRONAT, P., TORII, A., PAJDLA, T. SIVIC, J. NetVLAD: CNN architecture for weakly supervised place recognition. IEEE Transactions on Pattern Analysis and Machine Intelligence. 2017. IF 8.329 • HELLER, J., HAVLENA, M., PAJDLA, T. Globally optimal hand-eye calibration using branch-and-bound. IEEE Transactions on Pattern Analysis and Machine Intelligence. 2006, 38(5), 1027-1033. IF 8.329
H-index	15
prof. Ing. Michael Šebek, DrSc.	Position: Head of Cyber-Physical Systems Department
Research focus	Design and development of next-generation airplanes and space vehicles, multi-vehicular systems such as platoons of cars without drivers, formations of unmanned aerial vehicles, adaptation and learning over complex networks, modelling and control of electric power generation, network transmission and electricity market, micro- and nano-manipulation including non-contact manipulation by shaping force fields, control for electrokinetics and microfluidics, identification and control of nano-scale structures, and smart surfaces with adaptive topography. Research into new methods of applied analysis, computational mathematics and optimisation, general methods for simulating and modelling complex systems, including multidimensional simulation in materials engineering in areas ranging from nano to meso. Intelligent algorithms and computational infrastructure for the automatic collection, processing and interpretation of mass sensory data generated by remote sensing of Earth and other planets using spacecraft, automated space exploration etc.
Top results	• Henrion, D., Sebek, M., Kucera, V., Positive polynomials and robust stabilization with fixed-order controllers. IEEE TRANSACTIONS ON AUTOMATIC CONTROL. 2003, 48(7), 1178-1186. IF 4,27. Number of citation: 114 • Herman I - Martinec D - Hurák Z - Šebek M: Scaling in bidirectional platoons with dynamic controllers and proportional asymmetry. IEEE Transactions Automatic Control, 62 (4), 2034-2040, 2017.

	• Hengster-Movric K - Lewis FL - Šebek M: Distributed Static Output-feedback Control for State Synchronization in Networks of Identical LTI Systems. Automatica, 53, 282–290, 2015.
H-index	14
prof. Dr. Ing. Zdeněk Hanzálek	Position: Head of Department of Industrial Informatics (IID), Chair of the CIIRC CTU Assembly
Research focus	Scheduling, embedded system design, combination optimization, real-time control systems and industrial communication protocols.
Top results	• BUKATA, L., ŠŮCHA, P., HANZÁLEK, Z., BURGET, P. Energy Optimization of Robotic Cells. IEEE Transactions on Industrial Informatics. 2017, 13(1), 92-102. IF 6.764 • HANZALEK, Z.; JURCIK, P., Energy Efficient Scheduling for Cluster-Tree Wireless Sensor Networks With Time-Bounded Data Flows: Application to IEEE 802.15.4/ZigBee. IEEE TRANSACTIONS ON INDUSTRIAL INFORMATICS. 2010, 6(3), 438-450. IF 6.764. Number of citation: 58 • ŠPINKA, O., HOLUB, O., HANZÁLEK, Z. Low-Cost Reconfigurable Control System for Small UAVs. IEEE Transactions on Industrial Electronics. 2011, 58(3), 880-889. IF 5.160
H-index	11
prof. Ing. Tomáš Vyhlídal, Ph.D.	Position: Department of Industrial Production and Automation (IPA) - Head of Machine and Process Control Research Group
Research focus	Theory of control systems – spectral methods of synthesis for systems with transport delay. Design of oscillation damping systems, algorithms for control of flexible systems. Application of modern methods for process monitoring and control in the metallurgical industry, especially rolling processes and furnace technologies. Monitoring and control of indoor environment in historical buildings.
Top results	• Vyhlídal, T. - Zítek, P.: Mapping Based Algorithm for Large-Scale Computation of Quasi-Polynomial Zeros. IEEE Transactions on Automatic Control. 2009, vol. 54, no. 1, p. 171-177. • Michiels, W. - Vyhlídal, T.: An Eigenvalue Based Approach for the Stabilization of Linear Time-Delay Systems of Neutral Type. Automatica. 2005, vol. 41, no. 6, p. 991-998.
H-index	9
prof. Ing. Václav Hlaváč, CSc.	Position: Head of Department of Robotics and Machine Perception (RMP), Deputy Director of CIIRC CTU
Research focus	Computer vision, reconstruction of 3D scenes from 2D images, analysis of videosekvences, pattern recognition with emphasis to relation between statistical and structural methods, autonomous robotics, robotic manipulation with soft materials, industrial and other applications of the above.
Top results	• Antoniuk K., Franc V., Hlaváč V.: V-shaped interval insensitive loss for ordinal classification. Machine Learning, Volume 103, Issue 2, May 2016, pp 261-283.

	• Šonka M., Hlaváč, V., Boyle R.: Image Processing, Understanding, and Machine Vision, 4th edition Cengage Learning 2015, pp. 912 (1st edition Chapman & Hall, London 1993; 2nd edition PWS Boston, 1998, 3rd edition Thomson, Toronto 2008; Chinese translation 2003).
H-index	9
Ing. Libor Přeučil, CSc.	Position: Department of Robotics and Machine Perception (RMP) - Head of the Intelligent and Mobile Robotics (IMR) Research Group; Head of the Centre for Advanced Field Robotics (CAFR)
Research focus	Intelligent and autonomous robotics: • Control of self-guided autonomous vehicles of UGV and UAV kind • Advanced robot sensing and perception; uncertain sensory information processing and sensor fusion technologies for UAVs and UGVs • Robot localization, navigation and mapping and map/model keeping for uncontrolled, human and production oriented environments, natural and urban spaces, infrastructure-free environments in general. Life-long autonomy, runtime failure detection and recovery for robotics systems. • Multi-robot and swarm systems, covering hybrid human-robot cooperation and coordination problems, heterogeneous robotic swarms, etc. • Robot planning and scheduling and related optimization problems, advanced logistic and warehousing systems and applications of autonomy. • Advanced manipulation robotics, picking problems
Top results	• KULICH, M., MIRANDA-BRONT, J., PREUCIL, L. A meta-heuristic based goal-selection strategy for mobile robot search in an unknown environment. Comput. Oper. Res. 2017, 84, 178-187. IF 2.600 • FAIGL, J., PREUCIL, L. Inspection planning in the polygonal domain by Self-Organizing Map. Applied Soft Computing. 2011, 11(8), 5028-5041. IF 2.612.
H-index	7

For each of the researchers listed above, a structured CV including a research profile is provided in Annex 28 Reference CVs, prepared according to ERC grants CV templates.

TOP 10 CIIRC CTU Publications

Publication	Number of citations (WOS)	IF
Strasser, Thomas; Andren, Filip; Kathan, Johannes; et al. A Review of Architectures and Concepts for Intelligence in Future Electric Energy Systems IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS Volume: 62 Issue: 4 Pages: 2424-2438 Published: APR 2015	66	7.168
Hanzalek, Zdenek; Jurcik, Petr Energy Efficient Scheduling for Cluster-Tree Wireless Sensor Networks With Time-Bounded Data Flows: Application to IEEE 802.15.4/ZigBee IEEE TRANSACTIONS ON INDUSTRIAL INFORMATICS Volume: 6 Issue: 3 Pages: 438-450 Published: AUG 2010	58	6.764
Vrba, Pavel; Marik, Vladimir; Siano, Pierluigi; et al. A Review of Agent and Service-Oriented Concepts Applied to Intelligent Energy Systems I EEE TRANSACTIONS ON INDUSTRIAL INFORMATICS Volume: 10 Issue: 3 Pages: 1890-1903 Published: AUG 2014	45	6.764
Prochazka, Ales; Vysata, Oldrich; Valis, Martin; et al. Use of the image and depth sensors of the Microsoft Kinect for the detection of gait disorders NEURAL COMPUTING & APPLICATIONS Volume: 26 Issue: 7 Pages: 1621-1629 Published: OCT 2015	10	2.505
Ugarte, Juan P.; Orozco-Duque, Andres; Tobon, Catalina; et al. Dynamic Approximate Entropy Electroanatomic Maps Detect Rotors in a Simulated At rial FibrillationModel PLOS ONE Volume: 9 Issue: 12 Article Number: e0114577 Published: DEC 9 2014	9	2.806
Prochazka, Ales; Vysata, Oldrich; Valis, Martin; et al. Bayesian classification and analysis of gait disorders using image and depth sensors of Microsoft Kinect DIGITAL SIGNAL PROCESSING Volume: 47 Pages: 169-177 Published: DEC 2015	8	2.337
Macas, Martin; Moretti, Fabio; Fonti, Alessandro; et al. The role of data sample size and dimensionality in neural network based forecasting of building heating related variables ENERGY AND BUILDINGS Volume: 111 Pages: 299-310 Published: JAN 1 2016	3	4.067
Sara, Jaskanwal D.; Sugrue, Alan; Kremen, Vaclav; et al. Electrocardiographic predictors of coronary microvascular dysfunction in patients with non-obstructive coronary artery disease: Utility of a novel T wave analysis program INTERNATIONAL JOURNAL OF CARDIOLOGY Volume: 203 Pages: 601-606 Published: JAN 15 2016	2	6.189
Dvorak, Jan; Hanzalek, Zdenek Using Two Independent Channels with Gateway for FlexRay Static Segment Scheduling IEEE TRANSACTIONS ON INDUSTRIAL INFORMATICS Volume: 12 Issue: 5 Pages: 1887-1895 Published: OCT 2016	2	6.764
Langari, Bahareh; Vaseghi, Saeed; Prochazka, Ales; et al. Edge-Guided Image Gap Interpolation Using Multi-scale Transformation IEEE TRANSACTIONS ON IMAGE PROCESSING Volume: 25 Issue: 9 Pages: 4394-4405 Published: SEP 2016	1	4.828

3.2. Brief Characteristics of the Project Partners

3.2.1. DFKI

German
Research Center
for Artificial
Intelligence

Company name	German Research Centre for Artificial Intelligence (DFKI) Deutsche Forschungszentrum für Künstliche Intelligenz GmbH (DFKI)
Registered office	Trippstadter Straße 122 D-67663 Kaiserslautern, Germany
Website	www.dfki.de
Establishment of the company	1988
Number of employees	485

Profile

The German Research Centre for Artificial Intelligence (DFKI) was founded in 1988 as a non-profit public-private partnership. It has research facilities in Kaiserslautern, Saarbrücken and Bremen, a project office in Berlin, and branch offices in Osnabrück and St. Wendel. In the field of innovative commercial software technology using Artificial Intelligence, DFKI is the leading research centre in Germany and, currently, is the world's largest research centre in its field in terms of number of employed researchers and the volume of research budget.

Based on application oriented basic research, DFKI develops product functions, prototypes and patentable solutions in the field of information and communication technology. Research and development projects are conducted in eighteen research departments and research groups, eight competence centres and seven living labs. Funding is received from government agencies like the European Union, the Federal Ministry of Education and Research (BMBF), the Federal Ministry for Economic Affairs and Energy (BMWi), the German Federal States and the German Research Foundation (DFG), as well as from cooperation with industrial partners. Twice a year, a committee of internationally renowned experts (Scientific Advisory Board) audits the progress and results of state-funded projects. In addition, BMBF evaluates DFKI regularly. The most recent assessment was again very successfully concluded in 2016.

Apart from the state governments of Rhineland-Palatinate, Saarland, and Bremen, numerous renowned German and international high-tech companies from a wide range of industrial sectors are DFKI's shareholders represented on the DFKI supervisory board. Among those industrial leaders are SAP AG, Sorfware AG, AIRBUS Group, Volkswagen, BMW Group, Intel, Google, Microsoft, Deutsche Telekom, etc. The DFKI model of a non-profit public-private partnership (ppp) is nationally and internationally considered as a blueprint for corporate structure in the field of top-level research and innovation.

DFKI is actively involved in numerous organizations representing and continuously advancing Germany as an excellent location for cutting-edge research and technology. Far beyond the country's borders DFKI enjoys an excellent reputation for its academic training of young scientists. At present, circa 500 highly qualified researchers, administrators and about 400 graduate students from more than 60 countries are contributing to more than 240 DFKI research projects. DFKI serves as a stepping-stone to leading positions in industry and successful careers as founders of spin-off companies. Over the years, 98 staff members have been appointed professors at universities in Germany and abroad.

DFKI has created over 70 start-up companies and spin-offs. Together with H. Kagermann (acatech) and J. Helbig (Bosch), Prof. Wahlster formed the term and the concepts behind Industrie 4.0 in 2011. DFKI was one of the German research organizations behind the national Industry 4.0 Strategy. Several departments of DFKI pursue research contributing to the implementation of the Industry 4.0 vision (e.g. Intelligent User Interfaces, Robotics Innovation Centre, Innovative Factory Systems, etc.). DFKI participates in dozens of national (funded by e.g. BMBF, BMWi) and international (funded by H2020, EIT Digital, EU Structural funds, etc.) research and innovation projects. Importantly, the industry (e.g. shareholders) provides substantial direct support to the research in this field.

Main Areas of Research and Development

DFKI is one of the founders and active participants the German national initiative Industrie 4.0, which triggered and inspired the global attention to this research area. Several departments of DFKI are actively involved in research projects and innovation activities in this field addressing various aspects of Advanced Industrial Production technologies. The most visible examples of research capabilities DFKI possesses in this field are:

- SmartFactory Laboratory - a development and demonstration centre for industrial applications on the basis of multi-vendor capability, where know-how of smart technologies of the future are exchanged between science and practice;
- A system of projects in the field of Human-Robot Collaboration (HyBr-IT, iHRC, HySociaTea, Hand in Hand, etc.);
- A flagship German project BaSys4.0 developing a comprehensive software architecture, which efficiently supports this transformation in the production processes via extensive integration of the IT components in the production plant;
- Smart business processes and knowledge services in Smart Production (the projects like APPsist, LEGO Smart Factory, BEinCPPS, etc.).

Relevant departments and research teams:

a) Intelligent User Interfaces Department

The Intelligent User Interfaces department develops the basics for multi-modal human-computer interaction and personalized dialogue systems integrating speech, gestures, and facial expressions with physical interaction. In the process, user, task and domain models are used to design dialog patterns that are as natural and robust as possible so as to be understandable, even in-group discussions or loud environments. By integrating virtual characters even emotions and socially interactive behaviour can be achieved as an output. A major focus is mobile user interfaces to location-based and context sensitive services especially for applications in robotics, automobiles and shopping situations as well as at theme parks and museums. In addition to the intuitive access to the Internet of Services and Things in the context of the semantic web, the department also studies barrier-free access to instrumented environments and networked worlds for seniors and the physically challenged. Our research results are also applied to innovative security solutions and self-defending networks. Significant for this research department is the intersectoral method of operation especially the cooperation of computer scientists with computational linguists and cognitive psychologists as well as the empirical and ergonomic evaluation of spoken dialog systems and multimodal user interfaces. The current activities in the domain of Human-Robot Collaboration in the context of the Industry 4.0 concept result in several innovative technologies demonstrating the application scenarios of collaborative work in hybrid teams (Mixed Reality Production 4.0, EyeBots, MADMACS, FactOpt, HySociaTea, etc.).

b) Innovative Factory Systems Department

The research group Innovative Factory Systems (IFS) has been active since 1998 in the field of user interface design for technical systems. A significant amount of experience in the design of user-oriented systems has been attained during this time from many – sometimes international – joint projects with industry. The benefits of this experience have been applied to the design of individual technical devices as well as to the unification of operability philosophies for entire product lines.

c) Institute of Information systems

The Institute for Information Systems (IWi) has more than 60 employees in which 20 are full-time employees. They are occupied in the field of application relevant research under the scientific head of Univ. Professor Dr. Peter Loos. Research and teaching activities include information and process management of industry, service providers and administration. The main focus is on the technology transfer from science into practice. The intersectoral structure of employees and research projects additionally furthers the exchange of expert knowledge from different fields. Moreover, the co-operation with small and medium-sized enterprises (SME) has a significant influence on the applied research work – projects in education and knowledge management play an important part as well. Thus, traditional teaching methods are revolutionized in virtual learning worlds. The Institute for Information Systems takes into account "the increasing amount of services in the economy through the support of service specific business processes with innovative information technologies and progressive organization concepts." Important topics include service engineering, reference models for public administration and the integration of industry, services and administration.

DFKI hosts the Innovation Laboratory for Hybrid Human-Robot Collaboration Team in Industry 4.0 (MRK4.0 – Mensch-Roboter Kollaboration 4.0). It provides a testbed environment for the implementation and evaluation of concrete use cases and acquired recently a set of 20 robots for experimentation and development. Robots from various suppliers are available for the focus topics:

- Intelligent man-robot collaboration in cyber-physical production environments
- Semantic technologies for service orchestration and process optimization in smart factories
- Multimodal, pro-active and situation aware production assistance using VR, AR, and mixed reality
- technologies
- Real- time production planning for Industry 4.0

The innovation lab MRK4.0 is under the scientific supervision of Prof. Wahlster, and run in close cooperation with CIIRC CTU. The platform **Power4Production** (http://www.power4production.de), jointly operated with ZeMA (Zentrum für Mechatronik und Automatisierungstechnik Gemeinnützige GmbH / Centre for Mechatronics and Automation Technology), offers the opportunity to exchange and transfer results as well as the testing and research of new processes and technologies in industry 4.0.

Figure. 1: German-Czech Innovation Laboratory for Hybrid Human-Robot Collaboration in Industry 4.0, Saarbrücken, Germany

At DFKI’s site in Kaiserslautern, the technology- Initiative SmartFactory-KL works on the future factory of industrial automation. It has created a development and demonstration centre for industrial applications on the basis of multi-vendor capability, where know-how of smart technologies of the future are exchanged between science and practice.

Quality of Research Activities To-Date

TOP 10 Research Results

Project title	SmartF-IT
Funding authority	BMBF, Bundesministerium für Bildung und Forschung, 01IS13015A
Short description	Software tools for multi-adaptive cyber-physical production systems: For the factory of the future technologies are developed with Industrie 4.0 that make the production of small quantities in real time with maximum quality, yet low cost manageable. Manufacturers thus can handle profitably fluctuating markets and global trends, offer a high number of variants or small series and meet individual customer requirements. The SmartF-IT project meets this challenge with the use of adaptive cyber-physical IT systems at all levels of production to achieve the introduction, implementation and operation of integrated production systems.
Website	http://www.smartf-it-projekt.de/?lang=en
Role in project	Coordinator, scientific lead

Project / IPR - SW	BaSys4.0 SW: BaSys 4.0 Virtual Middleware
Funding authority	BMBF, 01IS16022E, (2016-2018)
Short description	BaSys4.0 will develop a basic operating system for production systems, implementing the efficient adaptability of the production process as the central challenge of the fourth industrial revolution. The targeted solution is inspired by the open standard software architecture AUTOSAR as used in the automotive industry. Comprehensive software architecture and middleware, which efficiently supports this transformation in the production processes via extensive integration of the IT components in the production plant. An integrated process map with all data provided via a common interface is required to enable highly versatile process planning in real time. All service and production process data must be available in a standard format, expandable at any time. BaSys4.0 is creating the basic structured software architecture and generic IT components to connect the engineering controls of the separate components in a production plant, enabling the integration of complex production processes into one, comprehensive production system.
Website	https://www.dfki.de/web/forschung/iui/projekte/base_view?pid=979
Role in project	Project lead for one of three platforms

Project title	Hybr-IT

Funding authority	BMBF, 01IS16026A, (2016-2019)
Short description	Hybrid and intelligent man-robot collaboration, hybrid teams in changing, adaptable, cyber-physical production environments.
Website	https://intranet.dfki.de/research/projects/Project_1008
Role in project	Coordinator, scientific lead

IPR - SW	MADMACS Toolkit
Author	Tim Schwartz
Short description	The software allows creating flexible multimodal user interfaces with a free choice of modalities by integrating a variety of communication devices and protocols.
Website	https://madmacs.dfki.de/

IPR - SW	CPS for Smart Factories Toolkit
Author	Daniel Sonntag
Short description	The software/hardware outcome package consists of anomaly controllers for smart factories. It focuses on both open and closed-loop controllers in the robot domain and reporting/maintenance domain in manufacturing. Multimodal Multisensor Activity Annotation and Recording Tool. Fine-tuning deep CNN models on specific MS COCO category.
Website	http://www.dfki.de/smartfactories/

IPR - SW	Hybr-IT Software
Author	Anselm Blocher
Short description	Software assistant system for enabling hybrid (humans >2 and robots >2) teams planning and optimization in real production environments and with seamless integration with existing industrial infrastructures.
Website	http://hybr-it-projekt.de/

Project title	BEinCPPs, Business Experiments in Cyber Physical Systems
Funding authority	H2020, Factory of the Future, 2015-2018
Short description	BEinCPPS Innovation Action aims to integrate and experiment a CPS-oriented Future Internet-based machine- factory-cloud service platform). The final aim of this Innovation Action is to dramatically improve the adoption of CPPSs all over Europe by means of the creation, nurturing and flourishing of CPS-driven regional innovation ecosystems, made of competence centres, manufacturing enterprises and IT SMEs.
Website	http://www.beincpps.eu
Role in project	Cluster leader for a German pilot site

Project title	APPsist
Funding authority	BMWi, German Ministry of Economics and Energy, (2013-2016)
Short description	APPsist aims to develop a new generation of mobile, context sensitive, and intelligent adaptive assistance systems for knowledge and management support in smart manufacturing. The approach focuses on the qualification of the staff and attempts to compensate for any skills that may be lacking. The project partners develop an AI-based learning assistance system with the aim of facilitating continuing education for the staff.
Website	http://www.appsist.de/en/
Role in project	Development partner, workpackage leader
Application project partners	MBB Fertigungstechnik GmbH Festo Sales GmbH & Co. KG Brabant & Lehnert

Project title	HySociaTea
Funding authority	BMBF, Bundesministerium für Bildung und Forschung, 01IW14001
Short description	HySociaTea is an R&D project, which is embedded in the future strategy Industry-4.0 and deals with the development of flexible production and mission processes. The basic idea in HySociaTea is that the production environment of the future will consist of a team of humans closely collaborating with robots and virtual agents.
Website	http://robotik.dfki-bremen.de/en/research/projects/hysociatea.html
Role in project	Coordinator, scientific lead

TOP 10 DFKI Publications

Publication	Number of citations (WOS)	Impact factor
Cohen, Ernie; Dahlweid, Markus; Hillebrand, Mark; et al. VCC: A Practical System for Verifying Concurrent C THEOREM PROVING IN HIGHER ORDER LOGICS, PROCEEDINGS Book Series: Lecture Notes in Computer Science Volume: 5674 Pages: 23-+ Published: 2009	126	0.406
Schuller, Bjoern; Steidl, Stefan; Batliner, Anton; et al. Paralinguistics in speech and language State-of-the-art and the challenge COMPUTER SPEECH AND LANGUAGE Volume: 27 Issue: 1 Pages: 4-39 Published: JAN 2013	43	1.9
Georgiev, Iliyan; Krivanek, Jaroslav; Davidovic, Tomas; et al. Light Transport Simulation with Vertex Connection and Merging ACM TRANSACTIONS ON GRAPHICS Volume: 31 Issue: 6 Article Number: 192 Published: NOV 2012	36	4.088
Veit, Daniel; Clemons, Eric; Benlian, Alexander; et al. Business Models An Information Systems Research Agenda BUSINESS & INFORMATION SYSTEMS ENGINEERING Volume: 6 Issue: 1 Pages: 45-53 Published: FEB 2014	33	3.392
van Deemter, Kees; Krenn, Brigitte; Piwek, Paul; et al. Fully generated scripted dialogue for embodied agents ARTIFICIAL INTELLIGENCE Volume: 172 Issue: 10 Pages: 1219-1244 Published: JUN 2008	19	4.797
McKeown, Gary; Valstar, Michel; Cowie, Roddy; et al. The SEMAINE Database: Annotated Multimodal Records of Emotionally Colored Conversations between a Person and a Limited Agent IEEE TRANSACTIONS ON AFFECTIVE COMPUTING Volume: 3 Issue: 1 Pages: 5-17 Published: JAN-MAR 2012	146	3.149
Vinciarelli, Alessandro; Pantic, Maja; Heylen, Dirk; et al Bridging the Gap between Social Animal and Unsocial Machine: A Survey of Social Signal Processing IEEE TRANSACTIONS ON AFFECTIVE COMPUTING Volume: 3 Issue: 1 Pages: 69-87 Published: JAN-MAR 2012	111	3.149
Shafait, Faisal; Breuel, Thomas M. The Effect of Border Noise on the Performance of Projection-Based Page Segmentation Methods IEEE TRANSACTIONS ON PATTERN ANALYSIS AND MACHINE INTELLIGENCE Volume: 33 Issue: 4 Pages: 846-851 Published: APR 2011	8	8.329
Hertzberg, Christoph; Wagner, Rene; Frese, Udo; et al. Integrating generic sensor fusion algorithms with sound state representations through encapsulation of manifolds INFORMATION FUSION Volume: 14 Issue: 1 Pages: 57-77 Published: JAN 2013	35	5.667
Mossakowski, Till; Moratz, Reinhard Qualitative reasoning about relative direction of oriented points	20	4.797

TOP Researchers Relevant to the Project

Prof. Wolfgang Wahlster	Position: CEO of DFKI, Head of Intelligent User Interfaces Department
Research focus	Artificial intelligence and Computer Science incl. all aspects of intelligent, multi-modal interaction; spoken dialog systems and man-machine, esp. man-robot, interaction and collaboration.
Best results	Wolfgang Wahlster is the Director and CEO of the German Research Centre for Artificial Intelligence (DFKI) and a Professor of Computer Science at Saarland University. He has published more than 200 technical papers and 12 books on user modelling, spoken dialog systems, mobile and multimodal user interfaces, the semantic web, as well as the internet of things and services. He is a Fellow of AAAI, ECCAI, and GI. In 2001, the President of Germany presented the German Future Prize to Professor Wahlster for his work on intelligent user interfaces, the highest personal scientific award in Germany. He was elected Foreign Member of the Royal Swedish Nobel Prize Academy of Sciences in Stockholm and Full Member of the German National Academy of Sciences Leopoldina that was founded in 1652. He has been awarded the Federal Cross of Merit, First Class of Germany. He holds honorary doctorates from the universities of Darmstadt, Linkoeping and Maastricht. He serves on the Executive Boards of the International Computer Science Institute at UC Berkeley and EIT Digital. He is the editor of Springer's LNAI series and on the editorial board of various top international CS journals. In 2013, Wolfgang Wahlster received the IJCAI Donald E. Walker award for his substantial contributions, as well as his extensive service to the field of Artificial Intelligence throughout his career. Since 2009, he has been a member of the Executive Steering Board of the EIT ICT Labs of the European Institute of Innovation and Technology (EIT) with its German Co-Location Centre in Berlin.
Dr. Tilman Becker	Position: Senior Researcher at Intelligent User Interfaces Department
Research focus	Computer science, Speech Translation, Natural Language Generation, Multimodal Interfaces, Dialogue Systems, Multi-party Interaction and Semantic Technologies, Assistance Systems for Cyber-Physical Production
Best results	Participation at industry projects: IDS Scheer AG, UNL, Siemens, Deutsche Telekom Participation at publicly funded projects (national and European): Verbmobil, SmartKom, Comic, AMI, AMIDA, Talk, Value-IT, CyProS, Theseus, IKS, BIG, EIT Digital HII-CPS, RICAIP, DAMiAS Supervisor of 14 Bachelor, Master, and Diplom theses
Dr. Dietmar Dengler	Head of Department of Industrial Informatics (IID)
Research focus	Web-related information integration and extraction, web query languages and wrapper technology, personalized information services
Best results	• M. Bauer and D. Dengler: InfoBeans - Configuration of Personalized Information Services, MS-Word Version, IUI99, pages 153-156.

	• M. Bauer and D. Dengler: TrIAs: Trainable Information Assistants for Cooperative Problem Solving, Agents'99, pages 260-267.
Dr. Tim Schwartz	Head of Department of Robotics and Machine Perception (PMR)
Research focus	Multi-modal human-computer interaction and personalized dialogue systems integrating speech, gestures, and facial expressions with physical interaction.
Best results	• Yannick Körber; Michael Feld; Tim Schwartz, Pervasive Audio Playback in Cyber-physical Environments. In: Proceedings of 2017 Intelligent Systems Conference. Intelligent System Conference (IntelliSys-2017), September 7-8, London, United Kingdom, Pages 531-541, ISBN 978-1-5090-6435-9, IEEE, 2017. • Hybrid Teams of Humans, Robots and Virtual Agents in a Production Setting. In: Proceedings of the 12th International Conference on Intelligent Environments. International Conference on Intelligent Environments (IE-16), 12th, September 12-13, London, United Kingdom, 9/2016.
Mehdi Moniri	Head of "Intelligent Systems for Industry and Smart Distribution Networks" (ISI) Research group - Department of Intelligent Systems (INTSYS)
Research focus	Human robot interaction, Multimodal systems, Virtual and augmented reality, Human environment interaction
Best results	• Mohammad Mehdi Moniri; Andreas Luxenburger; Daniel Sonntag, Peripheral View Calculation in Virtual Reality Applications. In: Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing: Adjunct. International Joint Conference on Pervasive and Ubiquitous Computing (UbiComp-2016), September 12-16, Heidelberg, Germany, Pages 333-336, UbiComp '16, ISBN 978-1-4503-4462-3, ACM, New York, NY, USA, 2016. • Michael Barz; Mohammad Mehdi Moniri; Markus Weber; Daniel Sonntag, Multimodal multisensor activity annotation tool. In: Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing: Adjunct. International Joint Conference on Pervasive and Ubiquitous Computing (UbiComp), Pages 17-20, ACM, 2016.
Prof. Martin Ruskowski	Head of Intelligent User Interfaces Department
Research focus	Machine tools, artificial intelligence in automation technology, and the development of innovative control concepts for automation.
Best results	• Stephan Weyer; Carsten Harms; Martin Ruskowski. Seamless Integration of CPS-based Factories across various Engineering and Simulation Disciplines. In: Proceedings of International Conference on Advanced Technology & Sciences. International Conference on Advanced Technology & Sciences (ICAT-17), IEEE Latvia Section, September 13-15, Riga, Latvia, IEEE Xplore, 9/2017.

Prof. Peter Loos	Head of Institute of Information systems
Research focus	Communication systems for industrial applications, Information and data modelling, Software development, Implementation of communication systems
Best results	• Andreas Emrich; Tim Niesen; Sarah Rübel; Peter Fettke; Peter Loos, ErWiN: oder die Antwort auf die Fragen ... Was ist mein Geschäftsmodell? Wie funktioniert Digitalisierung? Wer kann mir helfen? In: Wissenschaft trifft Praxis, Vol. 8/2017, Pages 63-68, Mittelstand Digital, Berlin, 5/2017. • Patrick Lübbecke; Peter Fettke; Peter Loos, Sustainability Patterns for the Improvement of IT-related Business Processes with Regard to Ecological Goals. In: Marlon Dumas; Marcelo Fantinato (Hrsg.). Business Process Management Workshops. Business Process Management (BPM-2016), International Workshop on Sustainability-Aware Business Process Management, located at BPM 2016, September 18-22, Rio de Janeiro, Brazil, Lecture Notes in Business Information Processing (LNBIP), Vol. 281, Springer, 2017.
Prof. Dr. Antonio Krüger	**Innovative Retail Laboratory**
Research focus	Artificial intelligence, Media Informatics, Human Machine Interaction, Ubiquitous Computing, Geoinformatics
Best results	• Falling asleep with Angry Birds, Facebook and Kindle: a large scale study on mobile application usage, Matthias Böhmer, Brent Hecht, Johannes Schöning, Antonio Krüger, Gernot Bauer, 2011, Proceedings of the 13th international conference on Human computer interaction with mobile devices and services • A resource-adaptive mobile navigation system, Jörg Baus, Antonio Krüger, Wolfgang Wahlster, 2002, Proceedings of the 7th international conference on Intelligent user interfaces
Prof. Dr. Paul Lukowicz	**Embedded Intelligence**
Research focus	Development of innovative solutions in the field of cross-linked sensor-actuator-systems and energy- efficient systems. The main research fields are: social interactive systems, pervasive computing, wearable computing, cyber-physical system
Best results	• Orkhan Amiraslanov, Hymalai Bello, Gerald Pirkl, Peter Hevesi, Paul Lukowicz: WiCoSens: a wearable, intelligent color sensing platform for non-invasive storage shelf identification. ACM, New York 2017. • Abdul Mutaal Ahmad, Paul Lukowicz, Jingyuan Cheng: FPGA based hardware acceleration of sensor matrix. ACM 2016.

Prof. Dr. Volker Markl	Intelligent Analytics for Massive Data
Research focus	New hardware architectures for information management, scalable processing and optimization of declarative data analysis programs, and scalable data science.
Best results	• LEO-DB2's learning optimizer, Michael Stillger, Guy M Lohman, Volker Markl, Mokhtar Kandil, 2001, VLDB, 1, 19-28. • Nephele/PACTs: a programming model and execution framework for web-scale analytical processing, Dominic Battré, Stephan Ewen, Fabian Hueske, Odej Kao, Volker Markl, Daniel Warneke, 2010, Proceedings of the 1st ACM symposium on Cloud computing

Structured CVs of the above mentioned researchers are listed in Annex 28 Reference CV.

3.2.2. SIDAT, spol. s.r.o.

Company name	SIDAT, spol. s r. o.
Registered office	Zbrojnická 220/4, 162 00 Praha 6 Czech Republic
Offices	Jinonická 80, 158 00 Praha 5 Staré náměstí 9/8, 619 00 Brno Czech Republic
Website	www.sidat.cz
Establishment of the company	1990
Number of employees	80

Profile

SIDAT, spol. s r. o. is a traditional Czech company operating in the industrial automation market as a system integrator since as early as 1990. Even today it is still owned by Czech natural persons and it currently has 80 employees and a turnover of about CZK 250 million. The company provides its customers with comprehensive services and supplies related to manufacturing control systems, including manufacturing information systems. Its activities cover areas ranging from the design of the automation system concept or the design of electrical wiring to the design and implementation of automation components or industrial information technology meaning data collection and the monitoring of equipment efficiency and overall qualitative and quantitative production indicators.

SIDAT's key sectors mainly include the food and beverage, automotive industry, mechanical engineering and the production of building materials. Their own products allow not only to control the industrial production, but even to improve its efficiency and increase the operability of installed technologies. It is a certified application partner of a number of the world's leading companies. According to the requirements of its customers, SIDAT creates application software for process and visualisation levels, and provides a variety of other services such as industrial consulting, implementing the collection and archiving of process, production and operational data, or developing a customer requirements specification and a solution design.

SIDAT, spol. s r. o. also provides supplies of required materials, hardware, design, assembly and installation works, subsequent commissioning and post-warranty maintenance of supplied systems. At the same time, SIDAT, spol. s r. o. provides standardised and specialised courses and training for designers and workers of operators of automated production systems at its own training centre which has authorisation from Siemens. The company has offices in Prague and Brno. Approximately a half of its deliveries are for domestic end customers, the other half for foreign end customers.

The customers using the company's products include prominent national and international companies such as AGC, Behr, Carlsberg, Coca-Cola, Continental, ČEZ, ČKD, Danone, Heidelberg Zement, Heineken, Fuji Koyo, KRAFT Foods, Mondelez, Lafarge, Lasselsberger, Lhoist, Maersk Oil Qatar, Nestlé, PKN ORLEN, ProLeiT, PSP Engineering, PVS SABMiller, Siemens, MolsonCoors/Staropramen, Statoil, Valliant, TRW, Unilever, Viscofan, VW/Škoda Auto, ZENTIVA aj.

As early as the first half of the 1990s, the company established close pedagogical and professional cooperation with the Faculty of Electrical Engineering at CTU in Prague. Members of the company teach at the Faculty of Electrical Engineering, CTU, and students are offered traineeships at the company in order to prepare qualified workforce in the field of automation and informatics during their studies. Within cooperation with CIIRC CTU, SIDAT focuses on applying modern application know-how and on applying modern knowledge of control technology to automated system implementations for industrial practice. In addition, the company is one of the founding partners of the National Centre for Industry 4.0 (NCI 4.0) and is actively involved in developing the centre’s main activities.

The Position of the Partner on the Market from the Industry 4.0 Perspective

Since its establishment, the company has pursued its own research and development and it soon became one of the dominant organisations in the Czech professional landscape in the field of deploying industrial communication networks and control systems on DCS platforms. Here, the main focus was on applying the results of its own further development – the development of ‘reliability systems’. Since 2000, the company has begun implementing the first management information systems for production process control. Industrial informatics later became another key pillar of the company’s business. As in the field of industrial communication networks, the company also invested in the research and development concept of its operation in this field. Among other things, this is reflected in the fact that two of the company’s employees have defended their doctoral theses with this focus. Their results contributed significantly to the knowledge potential which the company applies in implementing integrated MIS/MES systems. Based on hundreds of projects implemented in a number of industries, the Company completed the first phase of the development and validation of standardised application tools in 2008. Their applications can effectively contribute to minimising the cost of acquiring or modernising production systems, significantly reduce the time required for putting such systems into operation, and optimise the costs associated with their operation.

Due to extensive experience with projects on platforms from various manufacturers, the company is also strong in integration projects, which provides a good basis for implementing projects with the principles of Industry 4.0. According to SIDAT’s experience to date, the transition to production in which the principles of Industry 4.0 are applied is not effectively possible without an adequate technical solution at the shop-floor level. This is because – by digitising processes at the shop-floor level – it creates the conditions for the data integration of production process with pre-production stages and other subsystems of the corporate structure. Also, it makes it possible to subsequently apply software production models, suitable simulation techniques, optimisation procedures and other principles of Industry 4.0. Recently being implemented, the examples of such projects include the production optimization in Viscofan Company or the control of parts production for the automotive industry at Fuji Koyo Company.

Benefits of the Project Partner Participation

Recently, simulation and optimisation tools that make it possible to create various production and user scenarios have been increasingly used in designing the production concept. The designed concept can then be assessed from different perspectives and it is possible to monitor the extent to which input criteria have been met. However, the transition from concept to implementation is usually done in the conventional way, using well-established procedures for creating programmes for industrial control computers and related IT systems. Programme specification is often based on informal and, in many cases, incomplete instructions from the investor. The progress of work on the solution and its final quality are then greatly influenced by the extent to which the implementer and the client manage to clarify the aforementioned ambiguities, and the solution phase at which these ambiguities are identified. The use of simulations helps identify ambiguities in early design phases, thus eliminating them from the subsequent implementation. Thanks to a semantic description of the different components that make up the entire production technology, it is possible to create an automated specification and also to generate test scenarios that will verify that the implemented equipment meets the specification.

SIDAT’s role in the present project is to verify the proposed parameters of overall production efficiency in a practical deployment. This activity will involve defining a validation application that will take place not only in the Testbed, but SIDAT will also look for a real-world commercial application where these new processes can be validated. SIDAT will also participate in defining requirements from the perspective of the system integrator while taking into account its application in practical implementation.

3.2.3. CertiCon, a.s.

Company name	CertiCon a.s
Registered office	Evropská 11, 160 00 Praha 6 Czech Republic
Website	www.certicon.cz
Establishment of the company	1996
Number of employees	340

Profile

CertiCon, a.s. is a Czech technology company involved in the innovation and development of software and hardware solutions for the areas of healthcare, telecommunications and the automotive and aeronautical industries. It collaborates with top technical universities and research laboratories throughout the European Union and implements projects all over the world. The company was established in 1996 as a spin-off of the Czech Technical University and it employs more than 340 experts, many of whom are holders of industry and other awards and certificates. The company provides services to customers that include private Czech companies (ProfConsult, Jablotron, Passengera, Apator Metra, ComAP), Czech branches of foreign companies (IBM, Asekol) as well as foreign European and American companies. CertiCon a.s. is a full member of the prestigious Austrian Christian Doppler Laboratory for “Software Engineering Integration for Flexible Automation Systems” and, together with TU Wien and the Austrian company Logi.cals, it participates in developing a general tool for the design and implementation of SCADA systems. The Laboratory’s activities, including CertiCon’s participation, are co-financed by the Austrian government. As an integral part of technology development on the one hand and support for technology transfer on the other hand, CertiCon a.s. cooperates with and is a founding partner of CTU’s Media Lab Foundation, and it also supports individual start-ups such as HealthHealm in Boston, Nova-met, s.r.o. in Šumperk or Passengery, s.r.o. in Prague. Along with its parent company SynergyCon, a.s., CertiCon a.s. has developed a long-term strategy to work with and provide professional and investment support to start-ups. The company also participates in the activities of the Centre for Applied Cybernetics III as a demonstration Centre for the transfer of the latest technologies from academia to industry.

Research and development for the company’s own purposes is implemented at the level of applied research within domestic and foreign grants. The most significant ones include the EU Integrated Project **ARUM (Adaptive Production Management)**, co-financed by the European Union under the Seventh Research Framework Programme (FP7 2012-NMP-ICT-FoF-314056) from September 2012 to

August 2015 and focused on production planning and scheduling in Airbus Industries, in Italian company Iacobucci and other companies. The consortium has been formed by 14 European companies and research institutes headed by Airbus Group as the main project coordinator (for details see Chap. 3.3.2).

The company director worked as technical coordinator of the entire project with a budget of over EUR 12 million, and CertiCon a.s. was responsible for the key work package within the project. The project was successfully completed in October 2015, and the company acquired extremely valuable know-how.

The Position of the Partner on the Market from the Industry 4.0 Perspective

CertiCon provides services for customers and also own industrial products within the Industry 4.0 and Smart City area.

Services for customers include development of a bespoke software, as well as consulting with process optimization and deployment of self-organizing units. CertiCon is one of the major pioneers of agent technologies in the industry, based on scheduling and planning software. We expect that the coordination of a large number of autonomous units will become increasingly relevant in the context of the development of the IoT. One of the main domain of CertiCon is finding optimal solutions by using a large number of autonomous units.

“Smart Cities” are one of several directions of the Industry 4.0. In this area, CertiCon has developed and nowadays offers a video camera system that can distinguish people, cars and other objects and understand their behaviour. For certain behaviours of these objects, the system may record or warn the operator of, for example, inappropriate behaviour.

CertiCon is keen to develop both optimization algorithms for industry as well as a combination of computer vision and subsequent responses to emerging situations that will coordinate between multiple entities with the greatest possible efficiency.

Benefits of Project Partner Participation

The main project benefits for CertiCon is the possibility to develop methods for optimizing and coordinating of entities. These tasks belong to the category of NP-complete math problems, which are very time consuming and which cannot be solved in real time with the current level of technology. CertiCon will seek and support the research and development of heuristic methods and the combination of linear and mixed integer programming with the aim to approximate the global optima in quasi-real time calculations (e.g. for the operation in acceptable time period) in selected scenarios.

We expect to improve the capability to coordinate large production units. While at present we are able to optimize the production of e.g. aircraft at the level of individual production stations, most of them only with series of several stations (production lines), in the future we expect the ability to optimize production at the level of production line groups, factories and entire industrial complexes. We also expect optimization with regard to production logistics, which is currently impossible due to the complexity of the problem.

We expect also benefits in terms of simulating manufacturing processes and improvement in production stability in addition to finding solutions closed to real-time processes. To be successful, it is necessary to produce a probability model of production line failures and logistical chain failures.

3.3. Strategic Supporters of the Project in Terms of the Network of Trust

3.3.1. National Centre for Industry 4.0

NÁRODNÍ CENTRUM PRŮMYSLU 4.0

Title	National Centre for Industry 4.0
Registered office	Czech Institute of Informatics, Robotics and Cybernetics, Jugoslávských partyzánů 1580/3 160 00 Prague 6, Czech Republic
Website	www.ncp40.cz
Established	2017 (September)
Number of members	founding: 15 new: 5 (as at 1 November 2017)

The National Centre for Industry 4.0 (NCI 4.0) was established through the official signing of a memorandum on 4 September 2017 at CIIRC CTU in Prague. The initiator of the centre's establishment was CIIRC CTU and, besides CTU, the main founding partners include Brno University of Technology, Siemens, Škoda Auto, the Confederation of Industry of the Czech Republic, the Chamber of Commerce of the Czech Republic, the Central Bohemian Innovation Centre and the South Moravian Innovation Centre. The founding partners are ABRA Software, DEL, Festo, KUKA Roboter CEE, SAP ČR, SIDAT and the VŠB – Technical University of Ostrava. In its relatively short existence, NCI 4.0 has been joined by additional partners, namely IBM Czech Republic, Factorio Solutions, a Czech branch of the US company We Refactor IT, Inc., as well academic partners – the University of West Bohemia in Plzeň and the College of Logistics in Přerov.

NCI 4.0 is an open national platform for anyone (companies and public institutions) who is interested in information about or collaboration within Industry 4.0 and it brings together academic and research institutions with industrial companies and professional organisations. In its initial phase, NCI 4.0 has been established as an institute of CIIRC CTU, which operates independently in both organisational and financial terms. Analogous or compatible infrastructure can later be created at Brno University of Technology and other universities.

The Centre was established with the objective of helping to introduce the principles of Industry 4.0 in the Czech Republic, especially in small and medium-sized enterprises. It focuses on sharing information about technological solutions and the impacts of technological progress on the society. The main objective is active support and development of close cooperation between academia and industry. For these and other purposes, seminars, conferences and workshops are organised focusing both on science and on popularisation.

The key technology infrastructure of NCI 4.0 is comprised of the "Testbed for Industry 4.0" as a new research and experimental institute for testing innovative solutions and processes for "smart" factories. CIIRC CTU provides the theoretical background and facilities – a cutting-edge research and educational institute that has a scientific atmosphere and provides conditions for world-class work and results.

Expression of interest in cooperation within the Cluster 4.0 project by the National Center for Industry 4.0 is documented in Annex 27 Letter of Support.

3.3.2.AIRBUS GROUP

AIRBUS GROUP

Company name	**Airbus Defence and Space GmbH (Airbus Group Innovations)**
Office	Willy Messerschmitt Strasse 1, 82024 Taufkirchen, Germany
Website	www.airbusgroup.com
Establishment of the company	1970
Number of employees	133 782

The Airbus Group (former EADS, rebranded in 2014) is a global leader in aerospace, defence and related services. In 2016, EADS generated revenues of € 66.6 billion and employed a workforce of about 133 782. The Airbus Group includes the commercial aircraft manufacturer Airbus, the world's largest helicopter supplier Airbus Helicopters and the Airbus Defence & Space division, the major partner in the Eurofighter consortium, the prime contractor for the Ariane launcher and producer of the A400M military transport aircraft.

Airbus Group Innovations (AGI), with sites in Germany, France, Spain, United Kingdom, Russia, Singapore and India provides world-class research capabilities in main aeronautics research topics such as materials, processes, structure engineering, systems and information technologies for engineering and innovative concepts. It is an operational and strategic asset for creation of added value for Airbus Group by driving innovation and sharing skills, facilities and research activities with Airbus Group divisions (as core actor within the Airbus Group Research and Technology network) and with external research organisations and universities as well as other industrials. Long term partnerships with external research organisations, and in particular with academic laboratories, is a key element of the innovation strategy of the Group and of AGI, evidenced in some areas by the creation of joint research laboratories.

The Airbus Group Innovations in Germany is legally an organisation within Airbus Defence and Space GmbH, the German subsidiary of Airbus Group. It has a permanent staff of about 300 people, 70 % of which are senior scientists. Its objective is to carry out research activities, which require a concentration of skills or equipment and which correspond to cross-divisions.

There are currently more than 8,000 Airbus aircraft in operation. Each aircraft is a complex product consisting of millions of parts that have to be assembled to perfection. Integrating innovative production techniques is vital for Airbus productivity. Today, digital mock-ups, laser projections onto aircraft bodies, and complex 3D environments have already been fully integrated into processes.

In the long-term, **Airbus Group** has been developing close cooperation with **CTU CIIRC**. This was confirmed by successfully obtaining support for the **ARUM (Adaptive Production Management)** project, which was co-financed by the European Union under the Seventh Research Framework Programme (FP7 2012-NMP-ICT-FoF-314056) from September 2012 to August 2015. The consortium has been formed by 14 European companies and research institutes headed by Airbus Group as the main project coordinator. The ARUM solution developed and evaluated in the European project includes business strategies applicable for the risk mitigation and management of small lot production and production ramp-up scenarios, knowledge-processing tools for the planning and scheduling of small lot production and production ramp-up using multi-agent technologies, and service-oriented architecture and platform for integration the ARUM solution and legacy environment. The ARUM solution provides a strategic planning function for proactive, dynamic line balancing the production taking possible risks into consideration and an operative scheduling function for real-time, reactive risk mitigation for disruptions appearing at the shop floor. The CIIRC ČVUT actively took part at the development of system architecture and interfaces and M&T for automation control and optimization.

The evaluation of the ARUM technologies *were made for three industrial use cases, the Airbus A350 system installation flow line at Hamburg (GE), aircraft galley systems produced at Iacobucci HF in Ferentino (IT) and at Infineon semi-conductor production in Dresden (GE). The ARUM solutions will significantly increase the production ramp-up and reduce the risks of delays due to disruptions. The benchmarking of the developed ARUM software tools with the legacy risk management solutions has shown their superiority in terms of proactive planning quality and reactive risk mitigation. Beside the validation of technical performance of the ARUM solution an intense end-user validation in internal and external workshops and demonstrations were done.*

Airbus Group currently cooperates with CTU CIIRC within the **DIGICOR (Decentralised Agile Coordination Across Supply Chains)** project, which was launched in 2016 by a consortium of 11 European companies and research organisations under the European Union programme for research and innovation Horizon 2020. DIGICOR aims to reduce the burden to setup production networks and collaboration between SMEs, to shorten the time to jointly respond to business opportunities and to support the integration into supply chains of large manufacturers. DIGICOR will also simplify the management and control of the distributed production and logistics activities.

Today's highly customized products in aerospace or automotive sector are developed in complex production and supply networks. In these networks, the collaborating companies often lack the governance rules and proper tools for coordinated planning, scheduling and control of production activities. As a result, the supplier policies of large OEMs in those sectors are very restrictive and focus on few large risk sharing partners. Direct collaborations with small companies and supplier networks are rarely supported. Therefore, ***the DIGICOR project*** *addresses the need for governance rules and knowledge protection for ad-hoc collaborations in production networks and SME clusters. The platform will use Industry 4.0 methods to develop an open ICT platform with tools and services to support the management and control of collaboration networks.*

Expression of interest in cooperation within the Cluster 4.0 project by the Airbus Group is documented in Annex 27 Letter of Support.

3.3.3. Škoda Auto a.s.

ŠKODA

Company name	ŠKODA AUTO a.s.
Registered office	tř. Václava Klementa 869, Mladá Boleslav II, 293 01 Mladá Boleslav Czech Republic
Website	www.skoda-auto.cz
Establishment of the company	1895
Number of employees	29 580

Based in Mladá Boleslav, ŠKODA AUTO a.s. is one of the Czech Republic's most important industrial companies. With a history dating back to 1895, it is one of the oldest car manufacturers in the world. At the same time, it is a modern, progressive and dynamically developing company that focuses on innovation in the development, production and sale of cars and components and servicing. The company mainly specialises in the development, production and sale of ŠKODA-branded cars, components, original parts and accessories and the provision of servicing. Since 1991, it has been part of the Volkswagen Group. Škoda Auto has three main production plants in the Czech Republic and, in addition, Škoda cars are also made in Slovakia, India, Russia and China in the various factories of the VW Group. In 2016, it had 29 580 employees and the company's net profit totalled EUR 951 million (CZK 25.7 billion).

The company cooperates with a number of universities in the Czech Republic (Czech Technical University, University of West Bohemia, Brno University of Technology, Masaryk University, VŠB – TU Ostrava etc.), the cooperation aims to bring the content of the studies closer to industrial practice. Every year, the company also invests tens of millions of crowns in projects concerning innovations in the field of technical development and production of cars, in which experts from ŠKODA AUTO a.s. cooperate both with academics and actual students.

ŠKODA AUTO, a.s. is one of the founding members of the National Centre for Industry 4.0. It uses this open platform, which is designed for sharing knowledge and experience with academic and industrial partners, as a basis for innovative projects intended for industrial applications. As the main partner of the Testbed for Industry 4.0 at CIIRC CTU, ŠKODA AUTO supports projects that establish links between science, research and industry, the sharing of good practice examples and expert know-how, as well as education in the form of professional training courses and workshops. The 'digital wall for production of the future' was created as a collaboration between the main partners of Testbed for Industry 4.0, namely ŠKODA AUTO and Siemens CR, in order to provide real-life demonstrations of Industry 4.0. In the first phase of the Testbed, the digital wall gives an understanding of the use of Siemens simulation software in production planning and control and provides an insight into the preparation and real production at the ŠKODA AUTO pressing shop, welding shop, paint shop and assembly.

The Laboratory R&D 4.0 was created in the new CIIRC CTU building as a collaboration between ŠKODA AUTO, a.s. and CTU. It currently has three main departments that focus on Human Machine Interaction (HMI), HW in the Loop (HIL) and the application of quality methods in the product development phase. The laboratory will mainly be used to support the development of driver assistance systems and to develop green mobility.

Expression of interest in cooperation within the Cluster 4.0 project by Škoda Auto a.s. is documented in Annex 27 Letter of Support.

3.3.4. Siemens, s.r.o.

SIEMENS
Ingenuity for life

Company name	Siemens, s.r.o.
Registered office	Siemensova 1 155 00 Praha 13 – Stodůlky Czech Republic
Website	www.siemens.cz
Establishment of the company	1890
Number of employees	over 10 000

Siemens is one of the largest technology companies in the Czech Republic and, for more than 127 years, it has been an integral part of Czech industry and a guarantee of innovative technologies. With more than 10 000 employees, it ranks among the Czech Republic' largest employers. The Siemens portfolio covers solutions for industry, energy, transport and public infrastructure, building technology and healthcare. The company employs more than 900 employees in research and development in the Czech Republic. The company operates eight development centres in the Czech Republic. Czech Siemens is a pioneer in the area of Industry 4.0 and Smart Cities, where it provides customers with a comprehensive solution for digitisation.

The company implements its vision of Industry 4.0 through its Digital Enterprise platform. The path to this digital enterprise leads through the promotion of digitisation in manufacturing and processing industries, i.e. at every phase of the value chain. This is closely related to the subsequent “smart” data analysis and evaluation, which improve decision making and increase productivity in industry. Siemens has already successfully implemented the ideas of Industry 4.0 at its manufacturing plants in Trutnov and Frenštát pod Radhoštěm.

Siemens currently cooperates with more than twenty secondary schools and universities that specialise in science and technical disciplines on scientific and educational projects, teaching, student internships and school equipment. It carries out joint research and development with Brno University of Technology, Technical University of Ostrava and Czech Academy of Sciences.

The Siemens Company is one of the founders of the National Centre for Industry 4.0 and is actively involved in building the Testbed for Industry 4.0. Within the framework of the National Centre for Industry 4.0, together with CTU in Prague and other partners from the academic and commercial spheres, Siemens contributes to the introduction of Industry 4.0 principles in the Czech Republic, especially in small and medium-sized enterprises. Concerning the Testbed facility, an open industrial laboratory is beeing jointly created to develop, validate and test new technologies, products, systems and concepts of Industry 4.0 in the pilot-operational conditions.

Expression of interest in cooperation within the Cluster 4.0 project by Siemens, s.r.o. is documented in Annex 27 Letter of Support.

4. COOPERATION UNDER PARTNERSHIPS BETWEEN RESEARCH ORGANIZATIONS AND THE APPLICATION SECTOR

"*The partnership cannot be signed or bought it can only grow from the mutual trust and benefits.*"

J. John H. Noseworthy, Mayo Clinic President and CEO

4.1. Establishing, implementing or enhancing cooperation under partnerships between research organizations and the application sector, including international cooperation

The Industry 4.0 initiative is a compelling example of success that is based on the integration of diverse approaches and on transparent collaboration between disciplines and sectors not only in the physical world but also in the cyber world. Without this interaction based on trust and openness, the objectives of Industry 4.0 cannot be successfully implemented. **The existing low level of interconnection between the public and private sectors in the Czech Republic has resulted in a great gap between the requirements and needs of businesses and the priorities and results of R&D institutions.**

Dead ends vs. secret entrances

Academia in the Czech Republic is in the continuous risk of dead-end journeys. In such a scenario, the academic institutions rise their priorities for the topics which had been abandoned by industrial actors years or even decades ago. The huge public investment and scientific opportunities can be misspent just because of such approach. The critical low amount of commercially effective R&D outcomes and only limited commercial success stories in the Czech Republic are therefore not a surprise. On the other hand, Czech academic institutions have unique opportunity and sources to focus all scientific directions, even those of high risk of failure. In such cases, sometimes, breakthrough discovery with essential contribution for the society and industry can be achieved – secrete entrance in the dead-end labyrinth. The theory of dead-ends and secrete entrances is applied in the project framework of Cluster 4.0 to prevent and mitigate the risk of failure and to strengthen the potential of benefits from the intersectorial collaboration.

In terms of long-term sustainability, the interconnection between research organisations' research activities and industrial practice is a key prerequisite. Collaboration with industrial enterprises on research projects makes it possible to implement research tasks while using real data and progressive production technologies. In addition, manufacturing businesses bring the necessary pressure on efficiency into research, due to high demands on short and flexible production cycles. Last but not least, companies help research organisations identify the right trends in industrial research so that academic institutions can more quickly identify potential dead ends in research tasks.

CIIRC CTU as an institutional prerequisite

With the respect to the role of the academia in a global challenge of the 4th industrial revolution, CIIRC CTU was established on the 1st of July 2013, as the integrating and collaborative platform for the prominent fields of Industry 4.0 - informatics, robotics and cybernetics. CIIRC CTU naturally interacts not only with the teams across CTU, but also with other academic and industrial organizations in the country and abroad. CIIRC CTU therefore serves as the open research and innovation platform for advanced technical science and education, technology development and transfer, integrating the knowledge potential of academia and industry that would otherwise be isolated and scattered.

This bottom up modernization approach was moreover supported by the high level decision. On the 22nd September 2014, the government of the Czech Republic resolved by the resolution no. 779 to support the exceptional project of CIIRC CTU. This was implemented by the decision of the Ministry of Education, Youth and Sports of the Czech Republic (MSMT) 3824/2014-5 to fund more than 1.2 billion CZK (EUR 40 million) for the investment of the new CIIRC CTU R&D Facility. The investment and the new R&D infrastructure itself, however do not provide a guarantee of the successful long-term sustainability of the Centre. Since 2013 CIIRC CTU has therefore been systematically setting the grounds for future scientific environment that will be capable to challenge the international excellence.

The new building of CIIRC CTU was opened in May 2017 with the assistance of the President of the Czech Republic Mr. Miloš Zeman and the Prime Minister Mr. Bohuslav Sobotka. This act meant a major milestone of the CIIRC CTU capacity building and its transformation from the investment start-up phase to the phase of implementation.

Up to this year CIIRC CTU, as described in the Chapter 3, has demonstrated even in its very start-up period the high level of excellence both in basic and applied research. Yet, the overall concept of intersectorial collaboration had been still missing.

Testbed for Industry 4.0** – **new space for collaboration

On September 4, 2017, CIIRC CTU introduced the first phase of the Testbed for Industry 4.0 (hereinafter called as Testbed) as a new research and experimental workplace for testing innovative solutions and processes for smart factories. Testbed for Industry 4.0 was established as the core research industrial facility as of the first of its type in the Czech Republic. The basis of Testbed is a flexible production line for concurrent production of several product types in a series of variants. It combines different technologies as additive manufacturing, machining, robotic manipulation, intelligent conveyor systems, human-robot cooperation, automated warehousing and others. It opens entirely new possibilities for the industrial partners by a valuable possibility to use its new research and experimental infrastructure.

The Testbed serves for testing innovative solutions and processes for smart factories. Thanks to the flexible interconnection of universal production tools and a sophisticated control system the same resources can be used to execute different operations, which are scheduled optimally as needed. Testbed comprehends technologies for manipulation and logistics (Kuka robot, 6-axis industrial robot, Montrac conveyor), production cell for machining (multifunctional tooling machine), workplace for human-robot cooperation (robots for handling and machining and for working with humans – Kuka robot, mobile wheeled robots, and collaborative industrial manipulator) and control system for Testbed (Siemens Simatic control system, Profinet communication system). There are also two 3D printers, one for printing from plastic, second for printing metal parts.

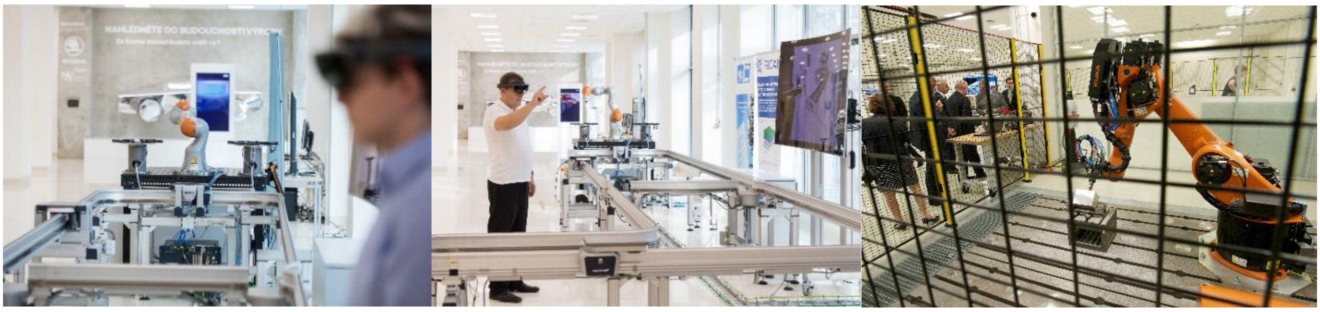


Figure 2: Testbed for Industry 4.0 in CIIRC CTU (augmented reality on the ground floor, heavy machines and robots in the basement)

A key aspect of Testbed is the existence of the so-called digital twin, which can be understood as a virtual product model, production process, and entire manufacturing equipment connected through a series of real-time sensors with a physical world in a cyber-physical system. With the help of advanced software, it is possible to implement a digital design of new products, simulate and virtualize the whole production line, optimize the product and the production process before starting physical construction. The cyber-physical space is enriched via augmented reality devices.

The Testbed equipment serves also for didactic purposes at the level of controller design, robot programming, high-level planning and scheduling etc. Researchers can also use flexible conveyor system with components for flexible grippers). Testbed by its nature represents the practical and very factual implementation of Industry 4.0 concept.

Testbed enables the companies an effective verification of the proposed model patterns of behavior based on the analysis of real data while using the physical high-end technical equipment.

Also, the Testbed can rely on the existing IT infrastructure of CIIRC, which consists of a 14-node computing cluster, virtualisation servers, a NAS network disk array with a total capacity of 600 TB, network infrastructure and a firewall system. The IT infrastructure of CIIRC is continuously retrofitted with additional elements (computing nodes, GPGPU cards, Omni Path or Infiniband infrastructure).

The Testbed is continuously retrofitted with additional modern technologies that are close to the current technology frontier. CIIRC CTU thus gradually creates a flexible infrastructure that can be reshaped depending on the current needs of industry. The next logical and absolutely necessary step is to complete this concept in the sense of a strategy to develop cooperation with the application sector (for details see Chapter 4.2). This is because the existence of that flexible experimental production infrastructure has boosted interest among enterprises (as evidenced by this project proposal).

In September 2017, CIIRC CTU – in cooperation with Brno University of Technology and the leading German research organisations DFKI and ZeMA – launched the prestigious European project 'RICAIP' that develops a brand new concept of geographically distributed, yet fully integrated industrial production. The project of the new international centre ***RICAIP (Research and Innovation Centre on Advanced Industrial Production)*** *aims to establish unique functional links between testbed facilities in the Czech Republic and Germany and to lay the foundations for the very first European research infrastructure in advanced manufacturing. RICAIP will enable enterprises to develop new manufacturing solutions in an experimental, yet full-featured manufacturing operation. The RICAIP project succeeded in the first phase of the H2020 Teaming Call. The consortium is currently preparing the project for the second phase with a view to implementing the project..*

Cluster 4.0** – **The pilot Project of the Network of Trust

The consortium of the Cluster 4.0 project, both its members (Sidat, Certicon) and supporters (Airbus Group, Škoda, Siemens, National Centre for Industry 4.0) bring a new driving force for the development of intersectoral cooperation in the area of Industry 4.0. As shown in Chapter 3, thanks to the Cluster 4.0 project many joint – more or less isolated – projects focusing on Industry 4.0 (from economic contracts to joint laboratories or participation in the National Centre for Industry 4.0) can get a common denominator within the complex relationship chain: **an interface between innovative businesses, academic technically-oriented institutes and global industry players, namely the issue of *the methodology of system integration***.

The growing complexity of production lines requires novel approaches to the organization of the design process. In such a way, the innovation focuses on an automatic decomposition and organization of the production systems to partial components that are realized by external system integrators. This approach processed automatically using semantic models of the relevant manufacturing domain provide superstructured level of collaboration across the sectors and value/supply chains boosting the ***Network of Trust*** (for the scientific description of the methodology of the system integration see chapter 5).

A network that has been designed as described above will make it possible to base research projects on data coming directly from their users, whether on the part of the customers or suppliers of the given solutions. This will make it possible to develop systems and methodologies for advanced production, including efficient diagnostics involving predictive maintenance tools. The greatest emphasis will be placed on developing procedures to data-link users of production technologies (e.g. Airbus Group, Siemens, Škoda Auto) with the suppliers of these technologies (e.g. SIDAT, Certicon). Thanks to close ties to leading industrial enterprises such as Škoda Auto, Airbus and Siemens, it is possible to aggregate data obtained from the various customer installations, analyse them and create methodological models that could not be constructed without such a large database. By joining other organizations (see chapter 6), we will continue to deepen the links to industry not only in the Czech Republic, but also in Europe within the consortium.

*As CIIRC ČVUT has cooperated with the Airbus Group with the frame of the two large EU Projects ARUM and DIGICOR aimed at adaptive production scheduling in assembling workshops with a remarkable pilot study carried out at the A350 fuselages workshop, Airbus is deeply interested in continuation in these system integration efforts. The proposed Cluster 4.0 project would enable to share the results of current research activities – in addition to the already running projects – and to **extend scientific cooperation between Airbus, DFKI and Czech Technical University**.*

In the global economy, supply chains are not limited to the territory of any particular state. Therefore, solutions to support cooperation between companies should also be carried out in an international context. Both German research organisations and German companies are at the forefront of the digital transformation of the European economy and industry. Cooperation with partners who stand directly behind its creation is highly beneficial as it allows the quick adoption of new approaches to industry organisation within the fourth industrial revolution.

In this regard, the project may benefit significantly from the direct participation of a prominent German research organisation – DFKI. DFKI has extensive experience in implementing EIT Digital, a strategic European project for intersectoral cooperation. EIT Digital delivers breakthrough digital innovations to the market and breeds entrepreneurial talent for economic growth and improved quality of life in Europe. It does this by mobilising a pan-European ecosystem of over 130 top European corporations, SMEs, start-ups, universities and research institutes (https://www.eitdigital.eu).

The European Institute of Innovation and Technology (EIT) *is an independent body of the EU whose objective is to contribute to the competitiveness of Europe, its sustainable economic growth and job creation by promoting and strengthening synergies and cooperation among businesses, education institutions and research organisations, and to create favourable environments for creative thought, to enable world-class innovation and entrepreneurship to thrive in Europe. The EIT is an integral part of Horizon 2020, the EU Framework Programme for Research and Innovation. The EIT brings together the 'knowledge triangle' of business, education and research to form dynamic cross-border partnerships; Knowledge and Innovation Communities (KICs). Each Knowledge and Innovation Community operates in innovation centres called "co-location centres". KICs have co-location centres across the EU, which cooperate with regional centres in order to intensify the impact of their activities. In previous years, five KICs were established within the EIT. EIT Digital is one of them and, moreover, it is one of the most successful ones.*

Therefore, this project provides a truly unique pool of expertise and infrastructure of a German research partner (DFKI), a transnational corporations (Airbus, Škoda Auto, Siemens), and purely Czech entities from academia (CIIRC CTU) and industry (SIDAT, Certicon) and, in turn, it creates the conditions for transferring the driving forces and preventing Czech industry from lagging behind in the process of implementing the principles of Industry 4.0. Cooperation that interconnects users and manufacturers of production technologies is essential for efficiently implementing product/customer driven production system development and predictive maintenance systems, which are considered to be another key point in improving European competitiveness.

Support for education at CIIRC CTU through the participation of representatives of the application sphere

CIIRC CTU supports the education of master's and doctoral students in specialisations that include informatics, robotics and cybernetics. In line with legislation, teaching is mainly delivered within degree programmes and specialisations at individual faculties. Due to the very nature of CTU's technical focus, enterprises have a significant role in teaching students. The traditional and well-developed forms of enterprises' participation in teaching include both direct participation in courses within accredited degree programmes and specialisations, and supervision/critical review of master's and doctoral theses. This has a positive impact both on the quality of teaching and on the financial conditions and equipment for students (within the scope of instructions received from schools and under the conditions laid down by legislation and the Community framework for State aid for research, development and innovations, companies provide donations, instruments and equipment). However, new conditions of the industrial environment – especially adaptation to the new industrial revolution – bring new expectations, and new forms of cooperation are required (especially by enterprises but also by students). Therefore, the project will not only unlock but also efficiently exploit the potential for improving the quality of education through new forms of enterprises' involvement in teaching.

Within the context of the on-going Industrial Revolution, the project allows CIIRC CTU to focus on innovating the traditional concept of technical education. An integrated doctoral programme entitled Industry 4.0 is being prepared and its content will include priority topics of the Industry 4.0 initiative. The assumption (but not a necessary condition) is that – in addition to CIIRC CTU – faculty and research centres of both CTU and other important Czech technical universities will participate in the programme. The themes of the studies will be based on the actual needs of industry, thus allowing industrial enterprises to participate in education. Currently there is a lack of experts who are able to cope with the complexity of the Industry 4.0 in all its breadth, and graduates of this doctoral programme should become leading experts who are able to cover these issues.

Doctoral programme* "*Industrial Ph.D.*" – *proposed innovation in education

The studies will take place in Czech and English and students will be enrolled for study at CTU or another participating technical university, but their diploma will be issued jointly for both (or all) institutions. The supervisor will be appointed at the very beginning of the studies, the studies will include a common basis which will be studied by one study group each year, and the total duration of the studies will be four years. The common basis will include eight courses, including 6 mandatory and 2 elective courses that can be chosen by students according to their narrower specialisation. Lectures will be organised in semi-blocs, 4 mandatory courses will be provided by CTU and 2 by other technical universities. The condition for choosing elective courses is that at least one of the courses is lectured at a partner university (if it participates). In the third year of studies, it is recommended to complete a several-month internship at a foreign institution or in industry. The programme will be implemented in six specialisations that are key to Industry 4.0: Industrial automation; Industrial Informatics (including CPS, IoT, applied artificial intelligence); Economics, management, marketing; Robotics; Production and transport systems; Engineering support for complex systems.

In addition, a coordinated master's programme to support Industry 4.0 with Faculty of Mechanical Engineering, CTU is also in an advanced stage. This builds on the research and educational collaboration in implementing the edited textbook monographs entitled Artificial Intelligence 1–6 (publ. Academia Prague) in 1997–2013 (eds. V. Mařík, O. Štěpánková and J. Lažanský, all CIIRC CTU). The themes of the studies will be based on the actual needs of industry, thus allowing industrial enterprises to also participate in education at the master's level.

The project will make it possible to provide educational student placements in enterprises that implement Industry 4.0 principles in production. These placements will be centred around the project partners, as well as project supporters and other cooperating innovative institutions.

Based on the above stated, the joint activities will have an impact on the whole Czech Republic, whereas the main part of the activities, including the research activities in Chap. 5, will be implemented in the Czech Republic, also with regard to the development of the key research infrastructure of Testbed for Industry 4.0. As a matter of fact and in connection to the active involvement of the foreign partner, the complementary activities will be implemented outside the Czech Republic, namely in the research and testing facilities of DFKI in Saarbrücken, Germany.

Objective 1: Creating a functional intersectoral partnership – the Network of Trust, focusing on methodology of system integration as a unifying element of Industry 4.0

1.1 Analysing the international strategic partner's good practices in the development of key projects of intersectoral cooperation
1.2 Establishing a functional intersectoral network of important Industry 4.0 actors with support from global industrial partners and the NCI 4.0 knowledge platform.

1.3 Increasing the potential of the Testbed for Industry 4.0 as CIIRC CTU's key experimental infrastructure for research and development in the field of flexible advanced industrial production, including the development of industrial production systems.
1.4 Support for student fellowships in enterprises and academic institutions promoting the principles of Industry 4.0, including greater involvement of industry experts in Industry 4.0.
1.5 Regular evaluation of the progress of intersectoral partnership and network development.

Results and outputs of the activity	Target value for project implementation
Indicator 5 43 10 Number of supported cooperations Link to objectives 1.2, 1.3; the research objectives WP1, WP2, WP3 within Chap. 5 Feasibility study; supported key activity B	5
Indicator CO 26 / 2 00 00 – Number of enterprises cooperating with research institutions Link to objectives 1.2, 1.3, 1.4, 1.5; the research objectives WP1, WP2, WP3 within Chap. 5 Feasibility study; supported key activity B	2
Another result that is not reflected in indicators: As part of the project implementation, the cooperation with the representatives of the application sphere will be developed and deepened, especially with those who are in the process of implementing the principles of Industry 4.0. Output: student internships at the institutions from the application sphere visits to subjects from the application sphere organization of joint seminars with representatives of the application sphere Link to objectives 1.2 and 1.4; supported key activity B	 4 10 4
Additional other result that is not reflected in indicators: Analysing the international strategic partner's best practice in the development of key projects of intersectoral cooperation Link to objective 1.1; supported key activity E	1
Another other result: Output: foreign cooperating entities; expanding cooperation with Airbus and DFKI with direct and indirect participation in the implementation of the project Link to the objective 1.1; research objectives WP1, WP2, WP3 within Chap. 5 Feasibility study; supported key activity E	2

4.2. Preparation and development of long-term cooperation strategy

Genesis of the strategical planning for Industry 4.0

With the rapid changes in society, the methods we have previously used to solve many of our problems are less intelligent and effective. We have entered the Fourth Industrial Revolution, which is rapidly altering the face of our economy and our way of life. The worldwide Industry 4.0 initiatives aim to address those challenges of the global change to maintain the economics competitive, sustainable and responsible. They attempt to develop new paradigmatic approach for the innovation in the wide range of activities of human and hybrid teams beyond the industrial manufacture, and to provide the new quality for customers, beneficiaries and the society itself. The new solutions and strategical approaches are therefore needed for the whole range of areas, starting from educational, scientific and innovation approach up to the new way of thinking in the application sector, particularly in the industry. The success is however determined by the critical amount of human capacities in the educational and scientific sector sharing and enhancing the vision of Industry 4.0 towards the smart and responsible Society 4.0.

In 2016, the team of experts led by Prof. Vladimír Mařík, the director of CIIRC CTU, prepared on demand of the Minister of Industry and Trade Jan Mládek the comprehensive document on the ***National Initiative Industry 4.0***. The Government approved the document "Industry 4.0 – the initiative for the Czech Republic" in August 2016 as the national strategy with the long-term goal to promote new approach in industry, industrial development, research and education to even enhance the competitiveness of the Czech Republic. Thus, the Industry 4.0 framed by the initiative became a Czech national theme. CIIRC CTU has significantly contributed to the Industry 4.0 Initiative since its real beginning and now the Centre is acknowledged as the key academic partner of its successful implementation.

The Industry 4.0 national initiative assumes the need for greater synergy between academia, large, medium-sized and small enterprises, manufacturers and users of automation and informatics technologies. More than ever before – especially due to the high capital costs in implementing the principles of Industry 4.0, the speed of technological changes and standardisation – it is necessary to interconnect all actors affecting the manufacturing sector.

Integration of strategic intersectoral initiatives – the transfer of good practices from Germany

A number of countries have put together national initiatives in response to the Fourth Industrial Revolution. The German government's first vision on the future development of industry was presented at the Hannover Fair in 2011, with the German national ***platform "Industrie 4.0"*** being officially unveiled at the same spot two years later. "Industrie 4.0" is the centrepiece of the digital agenda for the German federal government, which has already earmarked EUR 100 million for further developing the platform through two support programmes of the federal Ministry of Economic Affairs; altogether the federal government has already spent around EUR 400 million on the initiative. In addition to the federal government, represented by the Ministry of Economic Affairs and the Ministry of Research, the platform has also brought on board industrial associations, unions and research institutions. Five working groups are working on further developing this national strategy, broken down into the following areas: reference architecture and standardisation, research and innovation, security of networked systems, legal framework, labour market and education.

From a technological standpoint, the centre of attention of "Industrie 4.0" is evolution from embedded systems to cyber-physical systems, with automated technologies focused on distributed systems in the vision and an assumption of methods of self-tuning, auto-configuration, auto-diagnostics, machine perception and intelligent support (Mařík et al. 2016, see also decision of the German cabinet „Drucksache 17/9261 des Deutschen Bundestages," 30. 03. 2012).

Owing in part to the activities within CIIRC CTU, the Czech Republic is in many respects following the example of Germany as the cradle of the fourth industrial revolution. There, the Industry 4.0 initiative – as described above – has been incorporated into many strategic documents at the federal, state and institutional level. In terms of the strategic management of the effects and impacts of Industry 4.0, Germany is almost five years ahead of the Czech Republic. The possibility to transfer knowledge and good practices from the German environment is therefore a key parameter to success.

The grounds of Czech-German R&D collaboration in the field of Industry 4.0 were set during the state visit of German Chancellor Angela Merkel in the Czech Republic. The direct positive effect was the signature of an MoU on R&D Collaboration in the field of Industry 4.0 between CIIRC CTU Prague and DFKI (core partners of the Project consortium) as part of the official top level state visit of the German Chancellor Angela Merkel in the Czech Republic in August 25, 2016 (Figure 3).

Figure 3: Founding fathers of the Industry 4.0 concept in Germany (W. Wahlster) and the Czech Republic (V. Mařík), behind them from left: Czech Prime-Minister B. Sobotka, German Chancellor A. Merkel, Rector of CTU P. Konvalinka, Czech Deputy Prime-Minister P. Bělobrádek, photo August 25, 2016.

Thanks to the project and specific role of CIIRC CTU in the process of creating and implementing the Industry 4.0 National Initiative, the Czech Republic can benefit from strategic cooperation with German partners – apply positive experience and avoid mistakes. **Germany's pioneering and, to a large degree, visionary activities in the field of Industry 4.0 came with certain pitfalls, which can be illustrated by the fragmentation of Industry 4.0 strategic platforms that currently operate in Germany** (source: Wolfgang Wahlster, DFKI 2017):

Figure. 4: Industry 4.0 strategic platforms in Germany

Experience from Germany shows that caution needs to be exercised when building new strategic platforms in the Czech Republic. Rather than diversifying and creating new ones, it makes sense to get involved on an equal footing in the already existing German driving forces.

As early as the summer of 2017, CIIRC CTU became a member of the ***international Industrial Data Space Association (IDSA)***, which brings together nearly eighty leading companies and research organisations that recognise the importance of sharing digital data for Industry 4.0.

The Industrial Data Space Association was founded in February 2016 during the constituent meeting at Fraunhofer Forum in Berlin. The basis for that was given by the research project of the Fraunhofer-Gesellschaft sponsored by the Federal Ministry of Education and Research (BMBF) that aimed at developing a reference architecture model for Industrial Data Space and piloting it in selected use cases. At the end of 2014, the Industrial Data Space initiative was jointly set up by the German business, political and research communities and ever since it has been pursuing its objective to establish both development and utilization at both European and international levels. As a user association the Industrial Data Space Association represents companies' interests. In particular, the association identifies, analyses and evaluates the companies' requirements for Industrial Data Space and supports the development of the reference architecture. Industry 4.0 is not the only topic the Industrial Data Space Association focuses on. The user association and its companies also address the digital economy in its entirety – industries, services and the retail trade. It is in close and direct contact to the representatives of the BMBF research project.

Industrial Data Space *is a virtual data space which supports the secure and certified data exchange and simple linking of data in business ecosystems on the basis of standards and by using collaborative governance models. Industrial Data Space forms a new foundation for industry 4.0 as the data owners do not lose data sovereignty, i.e. control over their own data. Data is only exchanged if it is requested from trustworthy certified partners. The data owner – i.e. the company – determines who is allowed to use the data in what way. As a result, the partners of one supply chain have joint access to certain data by mutual consent so that they can start something new, develop new business models, design their own processes more efficiently or initiate additional added value processes elsewhere, either alone or together. Industrial Data Space helps to utilise and spread smart service concepts.*

Thanks to strategic cooperation with DFKI, CIIRC CTU and the Czech Republic can benefit from Plattform Industrie 4.0 - the umbrella platform for the fourth industrial revolution in Germany. Moreover, the CEO of DFKI, Prof. Wahlster is the chair of one of the five Working Groups of this initiative.

Plattform Industrie 4.0

On 14 April 2015, Federal Ministers Sigmar Gabriel and Johanna Wanka launched Plattform Industrie 4.0 at the Hannover Messe trade fair. Following the first meeting of the platform's strategy group and steering committee at the end of April, the platform's administrative office was inaugurated in Berlin on June 3rd.

Plattform Industrie 4.0's primary objective is to secure and develop Germany's top international position in industrial manufacturing. The platform aims to promote digital structural change and to provide the consistent and reliable framework necessary for this. The more networked the economy becomes, the more cooperation, participation and coordination of all stakeholders is needed. The platform's goal is therefore to develop a consistent overall understanding of Industrie 4.0 through dialogue with businesses, trade unions, science and government.

The platform is steered and led by the federal minister for economic affairs and energy, Brigitte Zypries, the federal minister of education and research, Prof. Johanna Wanka, and high-ranking representatives from industry, science and the trade unions. Experts from business, science, associations and the trade unions develop operational solutions together with representatives from various federal ministries in thematic working groups. The platform's technical work is carried out in thematic working groups. The working groups develop and document precompetitive concepts on selected topics and specific recommendations for action that, when implemented, should ensure a competitive advantage for all partners in Germany (see www.plattform-i40.de).

National Centre for Industry 4.0 (NCI 4.0)

Modelled on ***Plattform Industrie 4.0***, the **National Centre for Industry 4.0 (NCI 4.0)** was established by fifteen partners through the official signing of a memorandum in September 2017 in order to help accomplish the objectives of the Industry 4.0 Initiative. The Centre aims to raise awareness about Industry 4.0 and develop close cooperation between academia and industry. NCI 4.0 is an open national platform for anyone (companies and public institutions) who is interested in information about or collaboration within Industry 4.0 and it brings together academic and research institutions with industrial companies and professional organisations.

The establishment of the National Centre for Industry 4.0 is another important step towards fulfilling the mission of CIIRC CTU – to pool the research potential of universities and industry in order to meet the needs of the Czech economy. NCP 4.0 thus becomes a natural nationwide platform for defining the strategic agenda of Industry 4.0 as a highly relevant society-wide priority across all sectors.

Partners and supporters of the Cluster 4.0 project are directly or indirectly involved in the National Centre 4.0 and – thanks to the project – they will become a driving force in the area of system integration methodology within the principles of Industry 4.0. The Cluster 4.0 project's strategic agenda, which has been developed by academic and industrial partners for the area of system integration, will thus become a component of the broader strategic direction of the fourth industrial revolution in the Czech Republic.

Thanks to the direct participation of the South Moravian Innovation Centre, the National Centre for Industry 4.0 provides useful synergies to the ***INDUSTRY CLUSTER 4.0*** *project, which was established in 2016 as an association of engineering and IT companies from the South Moravian Region, united to enhance their competitiveness and innovative activities, in particular through implementing the "Industry 4.0" concept (http://ic40.cz/en/).*

Intersectoral cooperation in the field of Industry 4.0 and strategic planning at CTU

In order to become a partner sought by industrial companies, CIIRC CTU had to go through a necessary process of building research infrastructure (in the form of a new building, modern technological equipment and cutting-edge research capacities) and creating an environment conducive to the development of partnerships. Based on the above, it achieved the initiation momentum for implementing new projects and partnerships, due to close cooperation with foreign research organisations also at the international level. Now, it is necessary to create a new common strategic research agenda for these purposes, so that this new platform makes it possible to address problems that are defined by industry's real needs. This is one of the key activities within this Cluster 4.0 project.

When creating a strategy for long-term cooperation with the application sector, the following principles need to be accepted:

- Seeking complementarities between research organisations and the private sector.
- Reducing the differences between activities that are motivated by scientific interests and commercial activities.
- Seeking balance in terms of research and application focus.
- Practical applicability of the results of joint research.

As many other public research institutions, CIIRC CTU still lacks a special separate strategic document that is specifically aimed at developing cooperation with the application sector and implementing the results of joint research in practice. This strategy is part of more broadly conceived documents, especially the Long-Term Plan of CTU (see mainly the Priority Objectives of the Long-Term Plan for 2016–2020 – priority objective 5: High-quality and relevant research, development and innovation) Also, it constitutes an ad-hoc part of the contractual documents of consortia for on-going large projects. In this case, however, only some activities are covered that do not offer a long-term systemic solution.

Currently, cooperation with enterprises is often dependent on personal ties and is implemented based on impulses coming from individual grant schemes. Cooperation needs to be further developed at the institutional level, and continuity of cooperation needs to be maintained even during periods when no grants are being implemented. The institutionalisation and systematic planning of relationships has a positive effect on its success. A lack of systemic and systematic uniformity in cooperation and knowledge transfer processes makes it difficult if not impossible to establish long-term cooperation between a research organisation and an entity from the application sector, and it also makes it impossible to create a high-quality legal and consulting framework within the research organisation, which is necessary for cooperation and knowledge transfer and which would simplify the entire process of applying research results in practice.

Through systematically building relationships and implementing specific projects in cooperation with the application sector, CIIRC CTU needs to set a strategy for developing this cooperation, which is targeted at actual results.

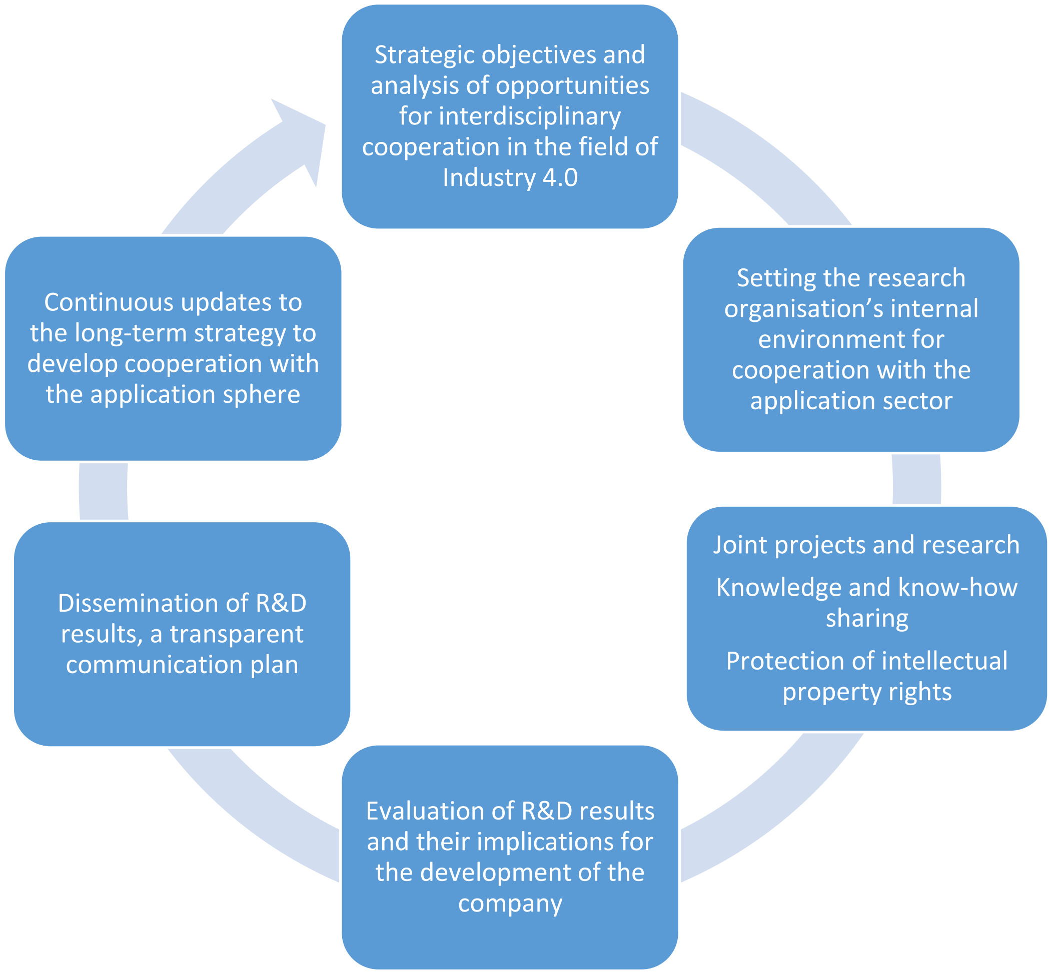


Figure 5: Strategic management cycle of the cooperation with application sphere

Within the project, the preparation of a strategy for cooperation with the application sector in the field of Industry 4.0 and system integration is operationalised through the following objectives:

Objective 2: Creating and implementing a strategy for intersectoral cooperation in the field of Industry 4.0 – system integration

2.1 Analysing Industry 4.0 strategic agendas from the German environment, selecting appropriate measures for the Czech Republic.

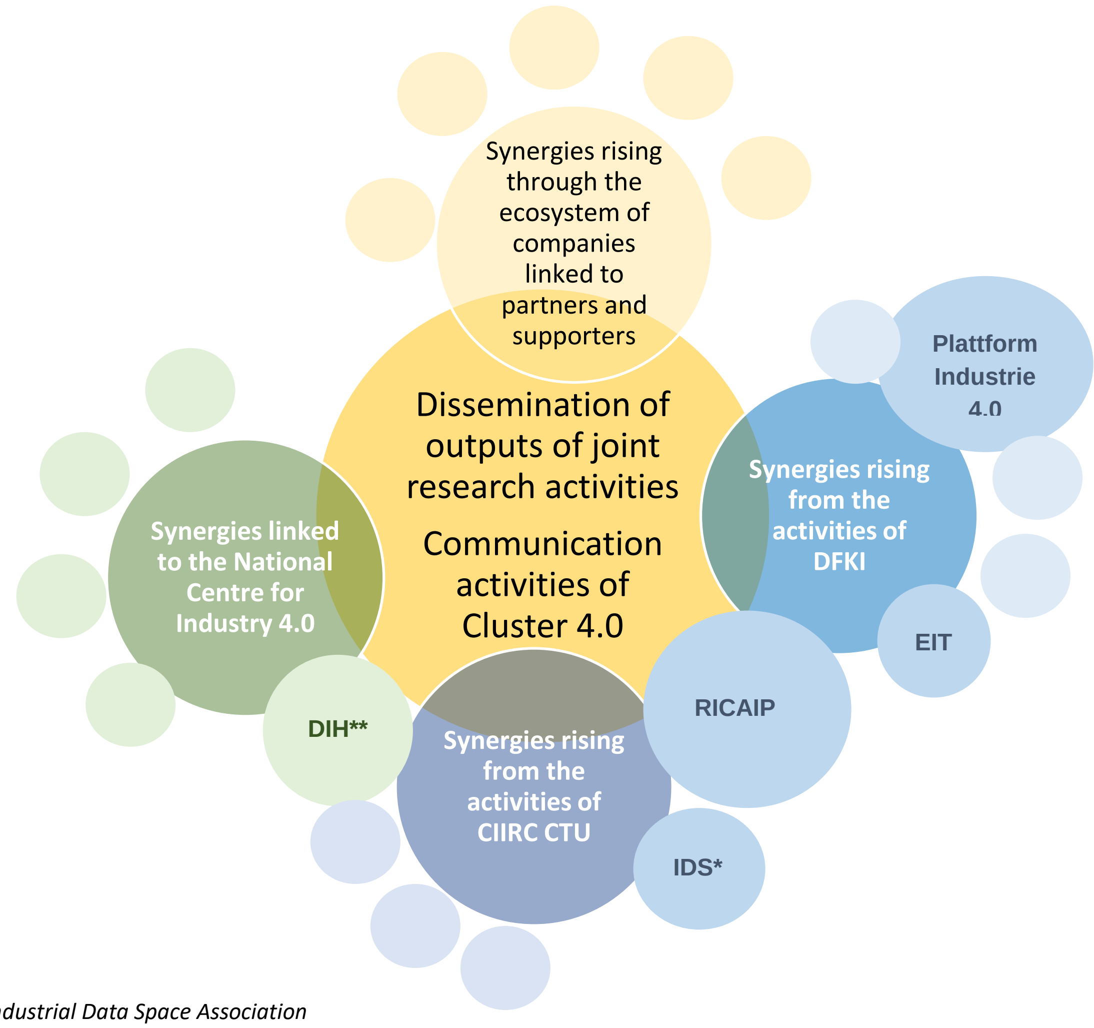
2.2 Formulating a vision and setting objectives in the area of cooperation with the application sector in the field concerned. Analysing the benefits of cooperation with the application sector with emphasis on the needs of society and transparent knowledge dissemination.
2.3 Creating a CIIRC CTU strategic document for knowledge transfer, technology transfer and intellectual property protection modelled on international strategic partners while taking account of industrial partners' good practices.
2.4 Setting a motivation system (financial and non-financial) and targeted internal communication for CIIRC CTU employees with a view to generating knowledge usable in innovations
2.5 Setting the principles for continuous updates to the long-term strategic plan for developing cooperation with the application sphere, because all these activities are in fact a permanent process.
2.6 Setting strategic cooperation between the consortium of the Cluster 4.0 project and NCI 4.0 bodies and partners – applying the project results and outputs within NCI 4.0 with a view to effectively disseminating them into society.

Results and outputs of the activity	Target value for project implementation
Indicator 2 15 02 Number of new products modernising strategic management systems in research organisations: A strategic document of CIIRC CTU for knowledge transfer, technology transfer and intellectual property protection modelled on international strategic partners while taking into account the industrial partners' good practices. The document will also contain the clarification of the rights and responsibilities in this process, furthermore the principles for continuous updates to the long-term strategic plan for developing cooperation with the application sphere, and an internal document that sets a motivation system (financial and non-financial) and targeted internal communication for CIIRC CTU employees with a view to generating knowledge usable in innovations. Link to the objectives 2.1, 2.2, 2.3, 2.4, 2.5, 2.6; research objectives WP1, WP2, WP3 within the Chap. 5 Feasibility study; supported key activity C	1
Additional other result that is not reflected in indicators: Output: an updated or newly created internal document on the application sphere governing the strategy for cooperation with research organizations in the field of R&D Link to the objectives 2.2, 2.5; supported key activity C	1

4.3. Activities leading to the dissemination of the results of joint research activity and its outputs

The Cluster 4.0 will pay special attention to dissemination activities in order to spread the knowledge on the Industry 4.0 concept, particularly on the methodology of the system integration and the aspects of the cooperation with application sphere. The main addressees of the dissemination activities are the R&D community, industrial companies, and the general public. Particular attention will be paid to inform about the research outputs, innovations and technologies developed within the Cluster 4.0, and research activities of the partners.

The Cluster 4.0 project will pay special attention not only to disseminating the research results and the innovations generated within this project, but also to the actual aspects of cooperation between research organisations and the application sector in implementing the Industry 4.0 concept as such. The topics that can be communicated are based both on specific results of cooperation on the given research task, and on aspects of the actual cooperation. Thanks to the partners participating in the project, it is also possible to take advantage of significant synergies arising from institutional networking and activities of the National Centre for Industry 4.0 (NCI 4.0) platform or from the involvement of the various partners in industry networks and projects. A significant multiplier effect can be obtained from these links for all communication activities of the Cluster 4.0 project.



** Industrial Data Space Association*
*** Digital Innovation Hub*

The common denominator of all communication activities will be to gradually build a community of entities and companies around core comprising not only the project partners, but – through the National Centre for Industry 4.0 – also its partners. These companies and institutions thus lay down the foundation for future followers. The process of attracting others will be in the first phase accelerated by systematic dissemination and exploitation actions followed in the second phase by a competitive advantage that will have the community members over the others.

The main channels supporting the dissemination of the outputs of cooperation with the application sector will be activities that are linked to the successfully developing National Centre for Industry 4.0 (NCI 4.0) platform. Building on the principles of cooperation between the consortium of the Cluster 4.0 project and NCI 4.0 bodies and partners (see Objective 2.6), a common strategic communication plan will be created in order to efficiently apply the project results and outcomes both within NCI 4.0 and outside toward industry, academia and general public.

NCI 4.0 ensures close cooperation between academia and industry, stimulates the exchange of experience and good practice and promotes the transfer of know-how to industry, including modern forms of start-ups and controlled innovations. NCI 4.0 will organise and co-organise conferences and practically oriented workshops, tours, thematic visits and professional training on these topics.

Through NCI 4.0, the centre's existing partners, potential partners and the wider professional community will be actively approached. This will also encourage them to directly or indirectly participate in national and international projects and also to intensify knowledge exchange within professional consultations. In accordance with NCI 4.0, it will be possible to do this using standard NCI 4.0 communication channels, especially its website, electronic information bulletin, thematic collections of papers and publications, thematic working meetings and expert fora such as the seminars, conferences and workshops mentioned above.

The ***communication priorities*** will be evolved around the main following topics:

1. **General information about Industry 4.0 and current Industry 4.0 initiatives**: Since the Czech Republic has one of the longest industrial traditions, it is important to strengthen and raise the awareness about the high importance of I4.0 for the Czech economy – to ensure the competitiveness of the Czech Republic in the global competition. But as a first step, the public (in Czech as well as in Germany and EU) and (small and medium-sized) enterprises have to be informed and sensitized for the subject I4.0 in general. This includes topics like the idea behind I4.0 as well as the potentials and opportunities it implicates. At the same time, possible existing fears about digitization have to and will be reduced by the provided information.

2. **Cluster 4.0 Project - general introduction**: an overview of the Cluster 4.0 project, its research goals and broader strategic aims of the project impact on the society as well as a compact overview even for non-conversant audience. The emphasis is on setting the strategy for the long-term plan to develop cooperation with the application sector.

3. **Cluster 4.0 Project - In-depth analysis and survey on the aspects of the cooperation between the research institutions and application sphere:** the selected target groups shall be informed about the Cluster 4.0 project itself and its aims, the set-up with information about the prospective goals and results of the project and the partners as well as R&D topics. By raising the awareness about the existence of the project and increasing the interest in I4.0, contacts between different target groups can be established. This can lead to open discussions with associations what in turn leads to intensified cooperation between the target groups.

4. **Research results** – **Methodology of System Integration:** dissemination and communication for both the industrial and scientific community has to be viewed under the prospect of the particular scientific results thus generating paper, conference presentations and new demonstrators. Later on also the intellectual property marketing and licensing.

5. **Best practice and use-cases:** Besides sharing information on innovation and approaches when implementing Industry 4.0, the objective is to transfer knowledge and experience towards the research

and industrial community. Naturally, the main information flow will lead from large multinational corporations to Czech small and medium-sized enterprises, from the German research community of Industry 4.0 towards the Czech one.

Communication tools and channels will be set up within the detailed Dissemination and communication plan. However, following tools are foreseen and recommended:

1) **Website**: new website will be created. The existing website of the partners and the National Centre for Industry 4.0 will be used for intense and targeted communication via electronic media and all information sources will be centrally accessible in an independent section of the CIIRC CTU's website.
2) **Newsletter / Fact sheets:** an electronic newsletter, published once a year, will be used to target interested researchers with relevant news, and also as a basis for communications with other stakeholders with emphasis on press releases and links to website articles etc.
3) **Presentation of the Cluster 4.0 project:** For various occasions (like visits to the particular institutes or participation in public events) it is useful to have a standard presentation at hand. Since this presentation will be compiled once and then can be used by all project partners, this results in a considerable reduction in the amount of work and time spent, as if each team member creates a new presentation for each event and enhances the identification of all partners.
4) **Seminars and workshops**: an important tool to tighten contacts to the industry and to establish new ones. Meetings and workshops should be prepared around information the topics listed in the above table and shall be focused on the open discussions of results as well as the impact on the society. Professional seminars will be organised both independently and in collaboration with the National Centre for Industry 4.0, but also in collaboration with third parties.
5) **Publications and journalistic articles**: publications in various newspaper can be used very well to increase the level of awareness of the project and to attract the attention of a broad target group. A distinction must be made between the scientific and general public dissemination. The scientific articles will focus on presentation of results at the top peer reviewed international journals. This will ensure project visibility and acknowledgement of the scientific results in the relevant fields.

   Whereas, a daily newspaper can be used to reach the target group of the general public (as well as the associations and politicy makers) and to gain attention for the Cluster 4.0 project itself or for the topic Industry 4.0 in general.

   The following journals are especially relevant for the scientific dissemination of the project: European Journal of Information Systems, IEEE Transactions on Engineering Management, IEEE Security & Privacy, ACM Trans. on Information & System Security, Journal on Computer Fraud & Security, ACM TOCHI, Human-Computer Interaction, Int. Journal of HCI, IFAC Control Engineering Practice, IEEE Transactions on Automation Science and Engineering; IEEE Transaction on Pattern Analysis and Machine Intelligence (IF=5.69), IEEE Transactions on Image Processing (IF=3.11), IEEE Signal Processing Magazine (IF=4.48), The International Journal of Robotics Research (IF=2.54), IEEE Transactions on Computers (IF=2.926), European Journal of Operational Research (IF=3.297), IEEE Transactions on Industrial Informatics (IF=6.764), Computers and Operations Research (IF=2.600) and IEEE Transactions on Systems, Man, and Cybernetics (IF=2.171) or in the proceedings of reviewed international conferences: ICRA - IEEE International Conference on Robotics and Automation (CORE B), NIPS - Advances in Neural Information Processing Systems (CORE A*), Conference on Information Control Problems in Manufacturing. Publication will typically accompany open software and reference data to facilitate the use of results and repeat experiments. The intellectual property of outputs with commercial potential will be effectively protected by a suitable method prior to publication.
6) **Presentation at international conferences**: the project partners will use opportunities to introduce the project results and experience at the renowned conferences and international expert symposia.

The indicative list of conferences: International Conference on Production Research (organized every 2 years by the International Foundation of Production Research); IFAC Conference on Manufacturing Modelling, Management and Control (also known as IFAC MIM); International Conference on Production Economics; IoT World Congress Forum; APMS (Advances in Production Management Systems), organized by IFIP (International Federation of Information Processing); other relevant conferences/events organized by EU.

7) **Excursions and demonstration workshops**: to increase the industrial awareness for the Cluster 4.0, first results and potential of these new approaches will be presented at mid-term of the project implementation, whereas approximately six months before the end of the project will be organized another workshop to identify the remaining gaps for industrial take-up and exploitation involving partners from the consortium, partners from the NCP4.0 and other potential commercialization partners and research organizations.

8) **Open days and events for the general public**: while excursions can be viewed as specialised tours for a narrowly defined group of visitors, events such as open days have an impact on more people. On the other hand, they are less targeted. However, they attract great attention of both the professional and the general public and, thanks to providing an immediate personal experience, they often have a significant impact on the understanding of the principles and context of the project and, by extension, on building closer ties with the target group. At the same time, these events offer a unique opportunity to demonstrate the progress and results of joint research in a real research environment.

9) **Consultation and Training Activities:** the consulting will be carried out with industry to directly disseminate the project outcome sand teach the main concepts and methods to interested stakeholders. As a measure of the impact for this activity, a minimum of 3 consultation sessions will be organised by the Cluster 4.0 partners during the duration of the project. In addition, the training material will be disseminated through project website and also through consulting sessions.

An overview of recommended communication channels by target group and main topic:

Topic Target group	Popularisation of the concept of Industry 4.0	Sub-aspects of cooperation with the application sector	Strategy for developing cooperation between RO and the app. sector	Specific outputs of the Cluster 4.0 project
Partner institutions of NCI 4.0	Website Professional seminars organised by NCI 4.0 Electronic bulletin	Professional seminars organised by NCI 4.0 Electronic bulletin Printed material	Prepared analyses and white papers Publications in collections of papers	Professional workshops and training courses Publications in collections of papers Printed material Thematic working meetings and consultations
Other industrial enterprises	Website Professional articles Presentations at conferences Presentations at trade fairs	Professional seminars and training courses organised by NCI 4.0 and partners Professional conferences	Prepared analyses and recommendations	Professional workshops and training courses Publications in collections of papers Thematic working meetings and consultations

Academia and research organisations	Website Professional articles Attendance at professional conferences	Professional seminars and training courses organised by NCI 4.0 and partners	Prepared analyses and recommendations	Publications in professional periodicals and journals
Professional community	Website Professional articles Attendance at professional conferences	Articles in professional journals	Website	Publications in professional periodicals and journals Excursions and open days
General public	Website Articles and appearances on national media Open days	Website Articles and appearances on national media Open days	Website	Website
Public sector incl. political representation	Website Professional articles Participation in conferences	Professional analyses and personal consultations	Prepared analyses and recommendations	Thematic working meetings

Objective 3: Disseminating the results of research cooperation, information on aspects of cooperation between research organisations and industrial partners and best practice in order to gradually build a professional community and contribute to cultivating an environment conducive to the development of further collaborations.

3.1 Creating a joint communication plan of activities in collaboration and compliance with NCI 4.0 in order to effectively apply the results and outputs of the Cluster 4.0 project.

3.2 Creating specific communication tools to raise awareness of the issue in question and of aspects of cooperation with the application sector, especially among academic and industrial entities.

3.3 Organising own and participation in new or existing professional events with the aim of actively presenting the outputs of the Cluster 4.0 project.

Results and outputs of the activity	Target value for project implementation
Indicator 5 10 17 Number of organised single events Presentation activities with direct connection to the project outcomes and results, e.g.: – A demonstration workshop for the partners of the consortium, partners of NCI 4.0 and other stakeholders during and at the end of project implementation – Professional seminars and excursions – Expert conference at the end of the project implementation – Presentation of project outputs at selected professional events (e.g. in the framework of an accompanying program at trade fairs and conferences)	20

– Expert seminars organized in cooperation with NCI4.0 focused on aspects of collaboration between research organizations and the application sphere in line with Industry 4.0 concepts Link to the objectives 3.1, 3.2, 3.3; supported key activity i)	

4.4. Development of joint research facilities, including the acquisition of infrastructure

The project will innovate cooperation between CIIRC CTU and research and development capacities of industrial partners, i.e. in terms of both content and form. Even today, CIIRC CTU – in collaboration with project partners and supporters – already operates joint laboratories within its infrastructure facilities, offers a residential research program and addresses other collaborative projects:

1) Joint CIIRC CTU-ŠKODA Auto laboratory (founding partner of the National Centre for Industry 4.0)
2) SIDAT as founding partner of NCI4.0
3) CertiCon – spin off
4) The NCI4.0 headquarters at registered office of CIIRC CTU

Thanks to the project, traditional forms of cooperation such as contract or collaborative research, joint research laboratories or expert consulting activities will be expanded to include a **shared flexible laboratory within the Testbed for Industry 4.0**, which is a key infrastructure of CIIRC CTU (for information about this key infrastructure see Chapter 4.1 a 5.6).

Upgrade of the Testbed for Industry 4.0 towards a shared laboratory

For the purpose of the scientific ambitions of the Project (see chapter 5), the current infrastructure represents just a basis of the core facility. Additional investment is therefore needed to meet the relevant topics of the Industry 4.0. The following listed equipment shows the general investment plan for the mid/long term perspective. Those items in bold represents the missing equipment to be purchased within the Project Cluster 4.0 (see also Annex 26 List of technology and IT equipment).

1) Automatic warehouse with automatically guided vehicles to move the parts from the warehouse to the production line,
2) set of **collaborative robots**, cameras and other motion-capture systems to build a specialized workplace for human-robot cooperation,
3) **enhancements of the flexible conveyor** to allow for planning of alternative routes and production schemes,
4) automatically guided vehicles to extent the conveyor system to more distant production islands,
5) separate production islands with specialized production equipment such as marking, pressing or tooling machines,
6) precise measurement devices such as laser trackers and 3D scanners to automate the process of quality assurance,
7) set of sensors and signal processing devices to deal with in-process diagnostics of tooling processes.

The above-mentioned vision identifies the gap between the current state and the future intended capabilities. Filling the gap would allow to cover more advanced topics such as agent-based production scheduling, machine-machine communication at the level of production adaptation, efficient and optimized human-machine cooperation, automatic quality assurance and its involvement in the product lifecycle.

> ***The shared laboratory of the consortium within the Testbed for Industry 4.0*** *will be operated in accordance with the Framework for State aid for research and development and innovation (2014/c 198/01) and based on Open Access principles. Given the infrastructure and institutional links, it is expected that there will be synergies between the Cluster 4.0 project and the H2020 project – RICAIP (Research and Innovation Centre on Advanced Industrial Production). Within the RICAIP project, CIIRC CTU and DFKI along with Brno University of Technology and ZeMA will establish a Czech-German research centre, with the objective being to establish functional links between testbeds in the Czech Republic and Germany and to lay the foundations for the very first European research infrastructure in the field of advanced distributed manufacturing. It is therefore assumed that a new international industrial hub for Industry 4.0 will be created, which will bring new intelligent, secure and sophisticated solutions for industrial production in multiple locations. The shared laboratory of the Cluster 4.0 project will constitute one of the subsets.*

Objective 4: Upgrade of key infrastructure of CIIRC CTU, the Testbed for Industry 4.0, towards a shared laboratory

4.1 Implementing tendering procedures for the technologies being acquired
4.2 Installing and commissioning the technologies acquired
4.3 Preparing and implementing scenarios (use cases) within a shared laboratory

Link to the supported key activity H – results and indicators are described in Chap. 5.

4.5. Preparation jointly developed international project applications

In terms of success in European grant competitions (FP7, Horizon 2020), informatics, robotics and cybernetics teams at CTU belong to the strong national average. The success rate of CIIRC CTU teams in international grants is (in terms of funding and number of submitted projects) is close to 20 % (above the national average). In terms of the European average, the absence or low number of international grants were CIIRC CTU acts as the coordinating institution is a big handicap, however. The Institute also need to increase competitiveness in H2020 projects focused on Industry 4.0, especially on the distributed advanced manufacturing. Moreover, CIIRC CTU has only one ERC grant awarded so far, which is also clear weakness.

CIIRC CTU to enhance its fundraising performance seeks for inspiration abroad. The grounds for robust knowledge transfer in the grant area and brand-new vision of the joint grant lab have been developed within the research collaboration between CIIRC CTUCIIRC CTU and leading German research organization DFKI. The importance of strategic cooperation with DFKI does not consist only in the transfer of know-how and best practice in R&D, but also in the organisation of R&D, procedures and processes, and internal logistics – were the grant support belongs. DFKI’s structure is relatively complex, but highly effective and functional nevertheless. The position of DFKI researchers is often allocated to a specific project management team.

Grant Lab strategy

The CIIRC CTU Project management office inspired by DFKI´s practice will set up a strategy to promote individual and cooperative highly competitive H2020 projects at CIIRC CTU to raise awareness about the grant possibilities (esp. ERC, Marie-Curie, FET-OPEN). The Grant Lab is an open platform for project managers from CIIRC CTU and partners´ institutions to cooperate on grant preparation and to develop joint collaboration. Main idea of the Grant Lab is based on the fact that grant managers are supporting researchers with necessary administrative work but that they are also idea makers and provide CIIRC CTU with creative tasks while preparing grant applications. Grant Lab is therefore a platform and also a physical office in the CIIRC CTU building, were the grant managers and specialists can meet, discuss future projects and mutually benefit from the joint cooperation. The Grant Lab strategy will help with the increase of competitiveness in H2020 projects focused on Industry 4.0, especially on the distributed advanced manufacturing where CIIRC CTU aims to act as the coordinator.

One of the main benefits for the successful development of Grant Lab strategy is undoubtedly the engagement of DFKI's chief project manager, Andrey Girenko, who will be thanks to the Cluster 4.0 project actively involved in administrative and project support of the Cluster 4.0 project team. **Andrey Girenko** holds the post of Senior R&D Administrator at DFKI. Since 2001, he has been an EU project manager both at the European Research and Project Office GmbH (until 2008) and at DFKI (ongoing). He has acquired, managed and evaluated more than 50 European projects in different programmes and delivered more than 25 training workshops on research methodologies, project and innovation management around the world. Dr. Girenko was a manager of FP5 Uptake Measure Agentcities.NET, managed FP6 i2Home IST project in the field of smart home environments for AAL, and led the activities on active engagement with older users in the framework of FP7 SIforAGE project. Besides, he was involved in such FP7 ICT projects as Metalogue and ROCKIT. The expertise in innovation management was obtained through the series of innovation projects such as EIT PRAF, FP6 K4CARE (EHR for home care, innovation manager), eContentplus MathBridge (business model developer). In 2013 Dr. Girenko served as an evaluation expert and rapporteur to the EC.

Objective 5: Increasing the amount of grant applications to the H2020 calls involving Industry 4.0 topics

5.1 Submitting at least four European project applications on the topic of Industry 4.0 in collaboration with DFKI
5.2 Award of at least two European projects on the topic of Industry 4.0
5.3 Developing a Grant Laboratory modelled on project-related practices at DFKI

Results and outputs of the activity	**Target value for project implementation**
Indicator: 2 03 12 Number of participations of supported research teams in international collaboration programmes Link to objectives 5.1, 5.2, 5.3; supported key activity G	2
Another result that is not reflected in the indicator: Output: submission of jointly processed international project applications during the project implementation period Link to objectives 5.1, 5.2, 5.3; supported key activity G	4

5. Research plan

The main research topic is Methodology of System Integration, which concerns the field 1AB9.1 - 1AB9.4 - Industry: Electrical Engineering and Robotics, namely 1AB9.4 Use of computers, robotics and its application.

5.1. Abstract

The growing complexity of production lines and rapid changes in the market demand require novel approaches to the organization not only of the production but also of the design process at various stages of the product life cycle. Additionally, thanks to the possibilities supported by social networks and mobile communications it is also much easier than ever before to stay in touch with the users of the products after they have been sold. The manufacturers can react to the feedback demanding new functional features or usability improvements. Those who can keep pace with such a rapid evolution are much more probable to be successful at the market. It puts additional demands on the production: its intelligent planning, construction, and commissioning, ramp-up and individualized production. Moreover, the flexibility of the production is a key factor that allows for mass customization and fulfillment of the changing demand. It is obvious that fulfilling such demands is not possible without an extensive support of the design and commissioning tools.

The research content is aimed to support the industry, especially the manufacturing companies including the Czech SMEs in implementations of the Industry 4.0 ideas. The core issue is the system integration of machine tools, transportation systems, robots, manipulators etc. The experimental development and prototyping of such solutions requires – as a rule – experimental usage of quite expensive equipment (e.g. several robots and machines).

To make the experimental efforts more efficient, the so called Testbeds as a specific phenomenon of Industry 4.0 are being used. A Testbed is an experimental, flexible manufacturing facility/workshop or its part where the physical equipment might be used for verification and testing of system integration projects. The testbeds are used not for the demo purposes, but for real development goals. They might be easily rebuilt quite often according to the needs of other companies.

The main goal of this project is to develop an integration platform which will be – as a matter of fact – extension of the first commercially available basic platforms (Siemens Mindsphere, ADAMOS, SAP Leonardo, Industrial Data Space etc.). The basic platforms are very good to start, but it is necessary to bridge the gap between these initial, quite generic and simple tools and the more developed/extended platforms needed and required by the customers to reduce the customization and implementation efforts.

The extended platform under consideration exploring the Service Oriented Architecture (SOA) enables to add specific modules to the basic platforms easily. These service providing modules are expected to support the system integration. These might be aimed at e.g. ontology knowledge exploration, simulation and modelling. The platform will leverage an additional layer of abstraction providing data-models for description of manufacturing components and a knowledge-base capturing the expert knowledge about relations between the components. An important aspect is a strong linkage to existing industrial software or open-source solutions which allows incorporating the project results into existing systems.

The platform should support the re-use of already verified and tested solutions, support migration of legacy systems and sharing best practices. Learning from experience is one of the key factors bringing an exciting advantage.

The developed platform will make the system integration development tasks much more efficient for the Czech SMEs, but also for integration of their manufacturing systems with the big manufacturers. It will significantly contribute to the (maybe yet informal) standardization in the field and speed-up the penetration of the Industry 4.0 ideas into the industrial practice.

The overall project objectives can be summarized in the following points:

1. The complex problem of the optimization of the production line design is decomposed into smaller subtasks respecting the distribution of the work among the end user and the system integrators. This makes the problem solution feasible and an optimal plant design is obtained.
2. The expert knowledge is transformed from the human experts to the expert system - this makes the process independent on the specific way of thinking of individual persons.
3. The specification of the implementation of the workstations is generated automatically, which makes the entire process more flexible and robust.
4. Iteration between the two levels of the design (plant design and design of the workstations) improves the content of the knowledge base.
5. The time needed for the introduction of a new production is strongly decreased if the proposed methodology is accepted.
6. The methods developed will be implemented in an integration platform that will utilize existing and obviously used software platforms suitable for industrial needs. Interfaces to established industrial software tools for simulation and optimization of production lines (such as Siemens Tecnomatix, NX etc.) will be also considered as a part of the platform.

In the rest of this chapter more details about the research are provided.

5.2. State of the Art

At today's plants, the plant setups for automated production are largely fixed. Machines are dedicated and set-up for certain products and the product-specific control logic is tightly coupled (and very often "hard coded") with the machine-specific logic. Similarly, the manufacturing operations management systems are rigid in their functionality and their means of communication. They are rigid enough, do not adapt easily to new production settings or to the needs of new value-adding or supporting services. Consequently, extensions and adaptations after the initial setup are very expensive. Integrating a new application scenario or applying the system to a different production use case is only done rarely and in particular cases. Even gathering production related data such as the information on machine status and availability requires expensive engineering efforts.

The goal of Cluster 4.0 project and the Cluster 4.0 Integration Platform (C4IP) is to create a unified, flexible software architecture for adaptable production systems, utilizing the service-oriented architecture (SOA) paradigm. SOA offers the capabilities for interoperability, autonomy, modularity, and flexibility needed for modern industrial automation systems [1]. Several attempts have already been made in this direction; the most relevant for Cluster 4.0 are the EU projects SIRENA, SOCRADES, PABADIS, and PROMISE. These projects formed the basis for SOA-based automation systems and gave proof-of-concepts that such systems are feasible. More recent projects like PLANTCockpit focuses on the integration of views on MES and ERP level for automation systems[2], whereas IMC-AESOP main interests are on integrating SCADA, MES and ERP levels for process industry, focusing on the System-of-Systems and distributed virtual factories aspects [3].

Cluster 4.0 has three core aspects, which are critical for operation and end user acceptance. They will form the major motivation and driving force for the Cluster 4.0 project and the development of the Cluster 4.0 Integration Platform (C4IP). These core aspects are:

- Flexible software architecture for adaptable production systems
- Increased level of modularization and leveraging the already existing SW systems as modules
- User Experience, reuse of existing solutions, and migration of legacy automation systems

The C4IP will be the base architecture system utilized by each project partner to achieve the goals of Cluster 4.0 and the common ground on which the Cluster 4.0 subsystem will meet and cooperate, as well as the Proof-of-Concept to demonstrate the capabilities and typical workflows of the Cluster 4.0 paradigm.

Each subsection dealing with one of the core aspects of Cluster 4.0 will feature a table summarizing the state of the art related to the Cluster 4.0 project and the progress beyond the state of the art provided by the project.

5.2.1.Flexible software architecture for adaptable production systems

The Cluster 4.0 project and the Cluster 4.0 Integration Platform (C4IP) will provide a flexible software architecture for adaptable production systems, integrating ERP and MES level systems naturally to the shop floor (control level). Cluster 4.0 will establish a strict separation of concern, where production sequences will be independent of the actual plant design and hardware-specifics of the utilized automation components, by encapsulating needed production capabilities, via the service-oriented paradigm, in the form of services. Semantically annotated production services and production sequences will enable automated planning and reasoning to choose the most suited service provider. The C4IP acts as an integration platform providing a common data model for the different automation system layers, enabling data transmission, data transformation and reasoning capabilities, seamlessly combining ERP, MES, and the shop floor level. New business models like PaaS (Production as a Service), big data analysis of shop floor behaviour, condition-monitoring and automatic remote maintenance, but also performance analysis feedback for shop floor equipment manufacturers will be available through the C4IP.

State-of-the-Art	Progress Beyond
In most cases industrial automation systems are designed, planned and implemented for a specific task, product, and/or process. High-tech products usually do not have such long life cycles that a plant can be profitably used. Currently this leads to large costs for re-programming the control software and needed down times for testing the new desired plant behaviour.	By defining and executing the plant behaviour via process descriptions (process recipes), the plant process can be abstracted from the hardware specific implementation and behaviour in the control software. Plant component capabilities are defined via services, which only expose their interface to the process and can thereby be reused and redeployed for new equipment without the need to change the process recipe.

Today typically, the automation systems are usually layered according to the automation pyramid, allowing only direct interaction between two adjacent layers usually leading to data loss if data from layers further away is needed, as each level has its own data structures and semantics. The automation pyramid is usually structured into the following layers from top to bottom: enterprise level (ERP), operations level (MES), process control level (SCADA), control level (PLC, IPC), field level (fieldbus, I/O access), and the process.	Cluster 4.0 is a key enabler for Smart Factories, enabling data loss free interoperability over all layers of the automation pyramid. The Cluster 4.0 Integration Platform acts as a common basis for data access and provides a shared semantic model for all data found in a typical plant automation system. As all data can be accessed and is available in a common data format and semantics, the borders of the needed soft- and hardware systems of producing enterprises are dissolving, enabling a natural combination of several level of abstractions into one unified platform.
Plant layout and plant component capabilities have to be taken into account when the automation control software is written. Changes in the plant or process have immediate impact on the control code, as component usage, component capabilities, and intra-process-logistics are interwoven with the plant process. This coupling forces the plant owner to recheck the program for now not permitted plant component usage, which is not feasible anymore, due to e.g. changed process parameters. This again leads to a cascade of other changes of probably now clashing uses of plant resources (transportation paths and/or manufacturing/process components). This happens even if the produced product stays the same.	In the Cluster 4.0 project means for the semantic self-description of plant components, automation services and process recipes will be developed. This enables the dynamic and decentralized industrial automation systems capable to separate the issues of process recipes, plant capabilities and hardware-dependent routines from each other, relieving the control software engineer, system integrator, and the plant operator from the burden of managing all these aspects by themselves. Also plant components can be utilized more efficiently as optimization can be used to create the most efficient process schedule, based on the requirements of the plant owner. This can be done via semantic reasoning and well known path finding and optimization algorithms, as long as machine-interpretable data of components, services, and process recipes are available. Additionally this enables automatic rescheduling and reorganization of a plant to provide graceful degradation and by that significantly reducing plant downtime.
The goal of the producing industry is to transform raw materials to finished or semi-finished products, generating added value due this transformation process, which are defined by domain experts. Although the production process is the key element for generating profit and added value, usually the domain experts are not able to change the production process without special training or help from control software experts.	The Cluster 4.0 project will enable the domain experts to reprogram the plant behaviour on a process recipe level. This is achieved by providing the domain experts with domain specific languages (DSL) which use terms and representations, which they are familiar with. The language elements of these will be based on the automation services provided by the automation components. With the C4IP capabilities mentioned above this process recipe will suffice to invoke all the necessary processes in the automation system to achieve the desired product automatically.

5.2.2.Increased level of modularization

The Cluster 4.0 project and the Cluster 4.0 Integration Platform will establish of concern, where production recipes are independent of the plant design and hardware-specific implementations of the automation components offered automation services. As the exact sequence of taken paths and I/O access are separated from the production recipe, modularization can be greatly enhanced. Automation components offering a certain automation service just have to comply with the automation services' interface and offered capabilities have to be announced to the C4IP. Differences in the service quality will be expressed via semantic annotations to the offered services. Thereby Cluster 4.0 enables automation component manufacturers to develop their products independently from actual deployment, protecting their IP and thus increasing the level of modularization of the offered automation components.

State-of-the-Art	Progress Beyond
The design and implementation of industrial automation systems is a quite complex and error prone task. As control software for industrial automation systems is usually a one-of-a-kind product for each industrial automation system, the system integrator usually sees no added-value in paying extra attention on modularization and/or code-reuse, apart from very basic and permanently recurring functions. This is paradoxical as there are a lot of logical recurring logical functions in typical automation plants (e.g., the heating/cooling of fluids, drilling, milling). Typically, these functions cannot be reused as they are highly interwoven with the physical representation of a plant component.	By applying the service-oriented approach to the area of industrial automation the logical production steps can be separated by their actual implementation. Recurring logical capabilities, building the services of the industrial automation system, can be easily reused for new industrial automation systems. The services have to be independently from each other so that usage of a service interferes, or is dependent of the usage of another service. Via these services a reusable and well-tested automation toolbox can be created, so the service user only depends on the service interface. Differences in an offered services' quality are expressed via semantic annotations, enabling higher-level orchestrators to choose the most suitable service provider.
Complex plant components usually come with their own closed-source software, providing the component vendors best-guess API or a proprietary interface to access the component. This usually leads to complex and inefficient usage of the component and/or extra costs to access process parameters of the component.	The Cluster 4.0 Integration Platform will provide one standardized way to access and use a wide selection of plant components, although C4IP will support and combine the most commonly used communication protocols in the industrial automation domain. Which communication protocol is used will be hidden from the C4IP user.
Plant components are usually integrated into and controlled by a centralized control program, making independent usage and control of a singular plant component impossible, especially as no knowledge what capabilities the component provides and how these capabilities are used is available.	Cluster 4.0 plant components feature a self-description of its capabilities, restrictions, and how to use them. This forms the basis for plant component autonomy and fast and flexible reconfiguration of plants and process recipes. These SW modules describing the capabilities of the physical components might be considered as a basis for virtual twins of the physical elements of the manufacturing facility. These twins play a key role in Industry 4.0 concepts.

5.2.3.User experience, reuse of existing solutions, and migration of legacy systems

The Cluster 4.0 project actively integrates existing automation solutions and legacy automation systems, as the success of the Cluster 4.0 Integration Platform is strongly dependent on end user acceptance. Actual state of the art solutions and trained automation personnel have to be encouraged to participate in the C4IP. In order to achieve this additional benefits have to be offered, as explained above, but more important is to utilize existing knowledge and hard-won skills, and to offer a clear and affordable migration path. In addition, Cluster 4.0 want to encourage potential users to use the new tools and the SOA paradigm emphasized in the C4IP, also adding new participants, like domain experts, to actively participate in the development process of automation systems. Cluster 4.0 therefore explicitly encourages and promotes the usage of existing solutions, but also strives to that the Cluster 4.0 paradigm is accepted. In order to bring these conflicting goals together, Cluster 4.0 will actively develop and promote migration paths to enable practitioners to switch to the Cluster 4.0 paradigm, but immediately gain benefits from the Cluster 4.0 project and the C4IP from the beginning. The change in thinking of the production systems designers and users should be achieved.

State-of-the-Art	Progress Beyond
Currently deployed plant automation and management systems are providing their own proprietary interfaces and tools, rendering it impossible to change a particular subsystem during the life cycle of a plant. The vendor-lock-in also engages if additional production resources are added afterwards, as usually these systems have to cooperate on an ERP or MES level. So even if the need for a change arise it is usually shunned due to the added costs, and the additional needed capabilities are somehow added to the existing system, adding additional complexity and creates hard-to-manage and -maintain systems.	The proposed Cluster 4.0 Integration Platform enables the plant operators to choose the best-of-breed commercial-off-the-shelf software for a certain task. Due its semantic connector design, any software can be easily and effortlessly added to the C4IP due to such a connector, as long as the software provides some kind of open API. By that means, it will be possible to switch operational components during the life cycle of a plant and to prevent the vendor-lock-in. This concept also allows the C4IP to be extended to future needs and new technologies used by the plant operators.
Recent projects dealing with the SOAs for automation systems have shown that an SOA approach is feasible and beneficial to the industrial automation domain. Unfortunately, these projects introduced many new technologies not well known to current practitioners in control software, which is why the acceptance on these new and working technologies was quite low [4]. Previous projects failed to facilitate the use of the well-known and commonly used technologies in the industrial automation domain, like IEC 61131-3, IEC 61499, OPC, OPC UA, several suitable fieldbus technologies like CIP, and the existing tools in which the automation engineers are well trained and comfortable with.	The Cluster 4.0 project actively seeks to integrate currently used technologies and tools into the Cluster 4.0 Integration Platform, enabling current practitioners to continue in the use of their tools and knowledge and only little additional training shall be needed to make full use of the C4IP. This does not only significantly cut the cost of additional training costs, but also enables the practitioners to use the tools which they are comfortable with. Standards like the PLCOpen XML data exchange format or AutomationML enables the C4IP to be compatible with a large range of typical automation engineering tools with little effort. Additionally well-known and proven tools can be used, which lowers the technical risks involved with the new technology.

Current automation software solutions exclude domain experts from the software development process. Typically, domain experts develop the production process, which is then handed to the control system expert, implementing the control software for the process. Changes in the process, which are expected to happen, automatically leads to changes in the control software, as the new process has to be translated into the control software's concepts and procedures.	The Cluster 4.0 project will enable the domain experts to effectively reprogram the plant and rearrange the processes based on the concepts and notation typical for the considered domain. Cluster 4.0 will permit the creation of domain-specific languages (DSLs), which can be used to represent the process steps of a certain domain. By creating production recipes in the DSL the Cluster 4.0 Integration Platform will be able to create all the needed intermediate steps and recipe enhancements, so that the production recipe can be executed on the Cluster 4.0 enabled plant.
There are several cloud-based platforms for data acquisition and analysis of industrial processes such as Siemens MindSphere, SAP Leonardo but also general platform such as AWS, MS Azure etc. may be suitable for certain tasks. Cooperation platforms such as Industrial Data Space or ADAMOS are also available, whereas IDS allows having semantic description of the data stored in the cloud. However, none of them allows matching of products and services.	The project is going to build on existing platforms and extend it in the way of description of product features, qualities and services that may be matched to create a valid production schedule. The matching will also generate simulation model that may be used to simulate the feasibility of the scenario. The simulation results may be taken as an input for a next iteration of the matching process.

5.2.4.References

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5.3. Link to the current research of the project partners

The partners of the Cluster 4.0 project have been involved in many projects and reference applications that are listed in partner profiles in chapter 3. Some of them deal with artificial intelligence, robotics, flexible production, production monitoring and management, etc. Solving challenges in those research areas contributed to forming the background and knowledge base necessary to formulate the objectives of Cluster 4.0. Most of the projects mentioned have had strong links to the industry, which demonstrate the capability of the research team to cope with industrial-size projects and in partnership with industrial companies to offer solutions that make the production better and more efficient.

In this section, some of those projects are described to provide a big picture of the background that has led to creating the consortium of the Cluster 4.0 project.

ARUM: Adaptive Production Management, FP7 2012-NMP-ICT-FoF-314056 project, financed by European Commission, 09/2012 – 08/2015. Participation of CIIRC CVUT.

> The project objective was to improve the process of production planning and control of complex products produced in small batches such as airplanes or ships. Among 14 partners from 7 countries there are also end customers such as Airbus or EADS.
>
> An industrial control system and method of controlling an industrial process are disclosed herein. In at least one embodiment, the control system includes an order system configured to receive an order from an external source and process the order to generate an order instance in accordance with an order ontology, at least one database storing a plurality of selectable generalized production plans and information identifying capabilities of a plurality of control entities, and a product agent in at least indirect communication with the order system, the at least one database and the control entities. The product agent receives at least one portion of the order instance, selects at least one of the generalized production plans, and communicates with the control entities to determine a production plan instance suitable for governing at least one aspect of an industrial process in order to satisfy at least one portion of the received order corresponding to the at least one portion of the order instance.

DIGICOR: Decentralised Agile Coordination Across Supply Chains. Horizon 2020-IND-CE project under ID 723336, financed by the European Commission, 10/2016 – 09/2019. Coordinated by Airbus Defence & Space GmbH (Germany). Participation of CIIRC CVUT.

> DIGICOR offers a technology platform, collaboration tools and services that allows manufacturing companies and service providers to create and operate collaborative networks across the value chain. The platform supports the integration of non-traditional, small but innovative companies into the complex supply chain of large OEMs. DIGICOR governance rules significantly reduce the burden of setting up collaborative networks and shorten the time to jointly respond to business opportunities.

AI4REASON: ERC Consolidator Grant no. 649043, financed by European Commission within the H2020 ERC programme, 09/2015 – 08/2020. Held by Josef Urban, CIIRC CVUT.

> The goal of the project is a breakthrough in what is considered a very hard problem in AI and automation of reasoning, namely the problem of automatically proving theorems in large and complex theories. Such complex formal theories arise in projects aimed at verification of today's advanced mathematics, verification of software and hardware designs, and verification of other advanced systems and technologies of today's information society. Recent advances of the team have shown that the performance of existing approaches can be multiplied by data-driven AI methods that learn reasoning guidance from large proof corpora.

R4I: Robotics for Industry 4.0, co-financed by EU and Czech Ministry of Education within call Excellent Research Teams in the Operational Programme Research from 06/2017 to 10/2022 under ID CZ.02.1.01/0.0/0.0/15_003/0000470. Held by CIIRC CVUT. The following topics are coped with in the project:

> The project deals with three areas of robotics with respect to Industry 4.0: Mobile robotics, intelligent gripping and grasping and multi-agent (networked) robotics.
>
> - Machine learning research will ease robot adaptation to new tasks and application environments, including robot-human cooperation. Effective and safe machine learning algorithms are an important precondition for autonomy in robotics, which has been recognized as a strategic bottleneck for smart industrial applications. The ability of robots to perceive and understand their environment is still very limited.

- Reliable sensing and perception methods for mobile industrial robots constitute the precondition for the use of robots in the Industry 4.0 applications. Additional challenges are present when it comes to the combination of perception and dexterity. The project focuses on the integration of perceptual systems with dexterous manipulation in the context of cooperative robots. The perception-action cycle can be simplified substantially if physical laws are explored smartly. Advanced perception, calibration and hybrid sensor-fusion will be studied in conjunction with mechatronic side of the problem.
- Strongly connected systems, which are the backbone of the Industry 4.0 concept, give rise to additional complexity due to the interaction of the subsystems. Profound understanding of the phenomena arising in the networked system is a necessary. Theoretical issues regarding "systems of systems" from the control-theoretic and cyberphysical point of view will be followed with special focus to two applied such as humans interacting with complex networks and multi-agent robotics. Additionally, research mechanisms constituting mechanical networks will be focused in two areas – controlled mechanical impedance to increase the mechanism's stiffness and mechatronic tricks to ease grasping and manipulation.

FLOPP: Factory of the future – flexible, optimized and tractable production systems. Financed by EU and Czech government under ID CZ.01.1.02/0.0/0.0/15_019/0004688 from 01/2016 to 09/2019. Coordinated by Eaton Elektrotechnika s.r.o. Participation of CIIRC CVUT.

The project objective is design, implementation and evaluation of new integrated computer technologies and architectures that allow to realize flexible, energy-efficient and agile production plan. Real-time information about the production status, current utilization of the machine or production line, availability of the material or energy requirements of the production processes. There is direct communication between the machines and cloud and is going to use intelligent sensors and actuators for autonomous decision at the level of individual logical units.

BaSys 4.0: Basic System Industry 4.0, financed by German Ministry for Education and Research, from 07/2016 – 06/2019. Coordinated by Fraunhofer Institute Kaiserslautern, participation of DFKI.

The project objective is development of a basic system for production facilities to achieve efficient flexibility of the production processes in conformance with the principles of Industry 4.0. Existing technologies and legacy systems are going to be integrated based on virtual middleware that coordinates available services and connects them together.

The industrial partners, i.e. CertiCon and SIDAT have been dealing with several research, development and integration projects such as intelligent detection of collision states in the railway transportation, intelligent production planning, agent-based control of production systems, production energy data monitoring and optimization, monitoring of the overall efficiency of the production systems etc. CertiCon has also participated in project ARUM and DIGICOR.

This list of project and experience with the topics relating to Industry 4.0, flexible production, decentralized control, production planning etc. shows that the partners have deep knowledge that is needed to solve project like Cluster 4.0. Applied research (e.g. ARUM, DIGICOR, FLOPP) building on top of the results of fundamental research (e.g. AI4REASON) provides the necessary background that links the existing knowledge to the proposed Cluster 4.0 project. Actually, it is an excellent opportunity how to utilize the existing knowledge and deepen it further to create an integration platform, which is proposed in this project. The experience of the industrial partners with respect to their reference projects and solutions links the integration platform closely to the industrial needs.

5.4. Research objectives, activities and results

5.4.1.WP1: Technology transfer

Due to the nature of the Cluster 4.0 project it is important to establish links between the project partners and to build the Network of Trust. In such a way the project outcomes may reach their final users and be implemented in industrial applications. Therefore the reconnaissance of the industry needs and requirements must be performed carefully. This is going to be done by defining use cases that are going to represent different manufacturing domains. Stress will be put on modular design with well-defined interfaces and strictly separated functionalities. This is going to allow further extensions to other manufacturing domains as well as to other partners of the Network of Trust. The current constitution of the project team (partners and strategic supporters) allows forming a solid base of the Cluster 4.0 Integration Platform (C4IP). It will serve as a software platform managing the necessary modules and hardware equipment to handle the manufacturing services and their interconnections.

The requirements have to be synchronized with C4IP as worked on in WP2, with the semantic description of the production systems and with the simulations as elaborated in WP3. Changes in the requirements or business motivation need to be quickly forwarded to the respective work package to deal with them in an adequate manner. In addition, knowledge gained from the work in the other work packages will be used to reconsider the importance and order of the collected requirements.

The project is also going to focus on coupling technical innovation created during the project with a suitable approach to create businesses for them. This enables extracting the full value of such novel approaches to automatic production. In order to support the business cases, this WP is concerned with standardisation activities. These include monitoring of existing standards and contributing to standardization bodies to influence the development of new standards as well as providing substantial feedback for new standardisation activities.

This work will allow comparison with state of the art competitors. Furthermore, these activities integrate and update the architecture and process design and description in WP3 and WP4. Finally, the expected project results will be classified according to Community Added Value, Social/Environmental Impact, and Technical/Economic Impact as well as corresponding exploitation aspects. The principal outcome of this part is a preliminary business model for such systems.

WP1 can be divided into three tasks that are described below.

T1.1: Use case definition and evaluation

This task is going to start by surveying significant user stories in close cooperation with the partners and strategic supporters. The diversity of the partner scope allows us to intercept correct representatives of the industrial needs, to abstract from domain-specific and user-story-specific requirements and to define general requirements that will serve as part of the specification of the system architecture for Cluster 4.0 Integration Platform. Consequently, use cases will be defined that will demonstrate the functionality of the C4IP. The first use case is going to be defined for Testbed for Industry 4.0 that is available in CIIRC as a test laboratory for various concepts of Industry 4.0. Testbed contains various physical equipment such as robots, conveyors, industrial controllers, and various software tools that comply with different phases of the product lifecycle. Testbed has been designed to allow research and implementation of various scenarios of flexible production.

Based on the experience from the Testbed use case in cooperation with the industrial partners other use cases will be searched for at their own production facilities are at their clients where the C4IP platform can be implemented and tested. The use cases will be defined while keeping the in mind that the final user must see the advantages stemming from the implementation of C4IP and that the advantages must be proven by tangible key performance indicators.
Regarding the evaluation, two types of KPIs are going to be defined for each use case: (1) process KPIs that demonstrate the effectivity of the production process gained due to the improved design procedures and optimization, and (2) design KPIs that demonstrate the effectivity of the design process such as the time needed to introduce new product features or time to introduce new production workflow.

Milestones and results

Milestone	Description	Month	Deliverable
M1.1.1	Generalization of the user stories to form a part of the system architecture specification for C4IP	M3	Report
M1.1.2	Extension of the Testbed infrastructure (see section 5.1.6)	M9	Report
M1.1.3	Definition of the Testbed use case together with the design KPIs	M12	Conference paper
M1.1.4	Implementation of the first prototype of C4IP in Testbed.	M24	Journal publication
M1.1.5	Demonstration of the improvement of the KPIs in the Testbed use case due to C4IP	M27	Report
M1.1.6	Definition of two use cases with industrial impact together with their process KPIs	M33	Report
M1.1.7	Implementation of the industrial use cases	M45	Conference paper
M1.1.8	Evaluation of the industrial use cases and their KPIs	M51	Journal publication

T1.2: Definition of the flexibility measures

One of the measures of the design is the measure of flexibility which may be expressed as the variability in the required sequence of operations to be executed, variability in the production path offered by the individual workstations, granularity of the operations of the workstations, product features such as their dimensions, material used, surface complexity etc. By including these measure into the semantic descriptions, we will be able to design flexible production lines that can change the production according to varying requirements on the production capacity, product variability or introduction of new product features and design characteristics.
Therefore, it is necessary to give attention to understand the notion of flexibility in the individual manufacturing domains and describe it in the context of the ontologies that describe the products and the production. An effort to find common flexibility measures across various domains will be done.

Milestones and results

Milestone	Description	Month	Deliverable
M1.2.1	Identification of the flexibility measure from the individual user stories created in T1.1	M6	Report
M1.2.2	Integration of the flexibility measure into the Testbed use case	M12	Conference paper
M1.2.3	Generalization of the flexibility measures	M24	Conference paper
M1.2.4	Integration of the flexibility measures into the industrial use cases from T1.1	M33	Conference paper
M1.2.5	Evaluation of the flexibility measures	M51	Journal publication

T1.3: Business model definition

This task covers definition of the business process that is behind the product lifecycle in relation to the activities in this project.
The proposed basic workflow is going to be elaborated in more details based on the discussions with the partners and strategic supporters. The main outcome of this task is to have business process defined in a way that allows sharing of successful results of integration, of individual methods, of integration platform and individual modules developed within the project to be used and re-explored in different commercial industrial use cases. Another outcome is to define measures and performance indicators that justify utilization of such advanced methods in industrial projects by showing their effectivity.

The evaluation measures include but are not limited to:

- The final technical performances in real industrial applications for SMEs,
- Reliability and repeatability,
- Human friendliness / Usability,
- Cost effectiveness,
- Integration of new processes, and
- Environmental impact

Detailed methods and criteria for the evaluation will be formulated in this WP.

Milestones and results

Milestone	Description	Month	Deliverable
M1.3.1	Outline of the business process aimed at sharing partial results	M6	Report
M1.3.2	Performance and effectivity indicators defined	M24	Report
M1.3.3	Indicators adapted to the industrial needs and business process described in details	M36	Report
M1.3.4	Evaluation of the process and indicators finished	M51	Journal publication

5.4.2.WP2: System Architecture

The Objectives of this WP are both the design and implementation of the Cluster 4.0 Integration Platform (C4IP) as well as implementation of a tool chain for the configuration of the micro-services in the design phase. The C4IP primarily addresses two major points: (i) the vertical integration of information systems used in manufacturing environments, and (ii) the semantically driven production control.

In the former case, the goal is to create a platform that simplifies the interconnection of various components on all levels of the enterprise information systems, including ERP and business intelligence, MES and SCADA, as well as machine-to-machine communication taking place between PLCs, embedded systems, smart tools, sensors, and actuators. The platform will help the user configure the connections to data sources hindering the intricacies of particular communication protocols, data schemes and network configurations. This is achieved by having an abstract semantic representation of the data source profiles and dedicated micro services advertising configure/read/write capabilities to access the data source. The C4IP will also support data transportation and transformation if there is a need to transport and convert data between incompatible network technologies and formats (e.g. between the binary OPC-UA in PLC and a non OPC-UA compliant SOAP used by web services in MES).

In the latter case the C4IP will provide a run-time environment for deployment of micro-services that control the production processes. These micro-services abstract from the operations offered by the manufacturing resources (Task 4.1) and advertise them in a semantic registry. The Service orchestration engine then executes the semantically described production recipes (Task 4.2) by negotiating schedules for individual operations with the micro-services.

In both these cases the security issues must be addressed. This ranges from basic network and data protection to process flow protection to protect the intellectual property of the manufacturing company against third parties, regardless of whether they have the rights to access the C4IP or not (e.g., to protect recipe data from machine vendors doing maintenance).

T2.1: Infrastructure Technology and Communication Protocols

The C4IP will build on top of existing, preferably open source technologies and platforms for IoT, which will be modified and extended according to the requirements of the industrial use cases identified in WP2. The integration of data sources accessible over various communication protocols used in automation systems (e.g., OPC, OPC UA) and business IT (e.g., message queues, ODBC) will be achieved by (i) designing a semantic-based representation of data source profiles including configuration parameters, (ii) designing communication protocols-specific data connectors to access the data sources (read/write operations) and (iii) designing the data source micro-services that abstract from the given data sources. These services register the configure/read/write capabilities for a given data source in a Directory service so that other services can discover them and communicate with them to perform the configuration and data reading/writing. The semantic abstraction and service based architecture provides an easy-to-use mechanism supporting future integration of new emerging communication protocols and data formats.
The run-time environment for micro-services will be implemented. The target will be on lightweight IoT protocols suitable for resource constrained devices such as CoAP, 6LoWPAN, MQTT, or ZeroMQ enabling running the micro-services close to the controlled hardware. The micro-services abstracting from manufacturing resources interact with the data source micro-services to get the real-time data from the shop floor and to control the actuators. Mechanisms for direct interaction of micro-services with the low-level real-time control, preferably based on IEC 61499, will be designed.

Milestones and results

Milestone	Description	Month	Deliverable
M2.1.1	Specification of the Cluster 4.0 Integration Platform	M12	Report
M2.1.2	First version of the Cluster 4.0 Integration Platform implemented	M24	Report
M2.1.3	Second version of the Cluster 4.0 Integration Platform implemented	M36	Report
M2.1.4	Final version of the Cluster 4.0 Integration Platform implemented	M48	Conference paper

T2.2: Runtime Service Management

The task focuses on the development of directory and an orchestration infrastructure technology that is required for integration and smart composition of micro-services in C4IP.

The Directory Service maintains the directory of micro-services and operations advertised by them. The semantically annotated description of services (using e.g. SAWSDL) will be used to enable the Service Directory to perform a semantically driven search for services suitable for execution of given manufacturing operations. The directory will also provide an authority maintaining the service-level agreements between service providers and consumers, including ensuring the quality and timeliness of service provisioning, redirecting to alternative services in case of SLAs violations, etc. The security features will also be embedded. The Directory Service will be utilized by both data source micro-services (registering read/write capabilities on data sources including the semantic description of the data structures) and production control services using semantic descriptions of manufacturing resources and their capabilities.

The Orchestrator Service is a micro-service itself that executes a given semantically described production process recipe by a composition of micro-services representing the production resources. The composition of services relies on the use of the Directory Service, which selects suitable services capable of performing required operations. This is supported using semantically enriched service descriptions (extensions to WSDL such as SAWSDL) that are matched with the semantically described operations from the production recipes. If needed, the C4IP ensures interoperability of diverse service implementations by data transformation to a neutral format.

The Orchestrator service can exist either in one instance only to mimic traditional centralized management of production control or can exist in multiple instances (each representing a single product or a batch) to achieve a better flexibility and robustness of the control system (the latter approach will be preferred).

Milestones and results

Milestone	Description	Month	Deliverable
M2.2.1	Specification of the directory and orchestration services	M9	Report
M2.2.2	First version of the directory and orchestration services implemented	M15	Report
M2.2.3	A publication on service oriented manufacturing submitted	M18	Conference paper
M2.2.4	Second version of the directory and orchestration services implemented	M27	Report

M2.2.5	A publication on results of the developed service-oriented manufacturing system submitted	M30	Journal publication
M2.2.6	Final version of the directory and orchestration services implemented	M32	Report

T2.3: Data, Information, and Knowledge Management

The key objective of this task is to design semantic data models of both the manufacturing resources and the production recipes. A method for creating semantic-based abstract descriptions of production recipes (workflows) will be developed. Attention will be paid to both discrete production (series of separated production steps) as well as process industries (based on batches). The description contains the type of requested manufacturing operations (to be matched with micro-services representing the manufacturing resources), including format of input and output parameters. The task will develop methods to semantically augment existing orchestration descriptions such as BPMN.

Another objective is to develop a generic production control ontology and a set of extending domain specific ontologies covering the specifics of the user stories as elaborated in WP1. The task will rely on the use of OWL and RDF technologies. The process descriptions will be used and executed by the Orchestrator service.

The data transformation engine will be implemented to support the conversion of data from the original format of a particular data source to a neutral, semantically annotated format, which will be designed to capture arbitrary data structures used in the production control domain. The engine will be instantiated in the data source micro-services to perform the conversion during the read/write request issued by other services. If the M2M communication takes place between two compatible protocols (like OPC-UA client with OPC-UA server), the data source micro-services are used only for configuration of the communication link and afterwards do not interfere with the data transfer (no conversion even takes place). The Linked data principles will be employed to represent and transport structured data, building upon technologies such as URI, OWL, JSON-LD and RDFa.

The integration of legacy systems and currently used automation system development software is crucial for the industrial acceptance of the C4IP. To achieve the integration of legacy systems, it is necessary to provide means to encapsulate the currently deployed functionality in form of semantic resources and services to make them available and useable to the C4IP. In cases where this approach is not feasible best practice rules have to be established to enable at least passive participation of the (sub-) component in the C4IP. In this case passive participation means to be able to signal component state changes to the C4IP. The bare minimum is being able to signal that a process was started or was ended. Besides from integrating deployed automation software, the C4IP also aims at integrating currently used automation system development software (e.g., Rockwell Studio 5000, Siemens TIA Portal, S3 CoDeSys, Beckhoff TwinCAT). Here, means have to be found to integrate those tools as well as the automation system software developed by these tools into the C4IP.

Within the framework of this task a software tool for creation and maintenance of the semantic descriptions of the manufacturing resources and the production recipes will be implemented. The tool will provide a user-interface supporting the plant operators to create and modify the semantic descriptions of the technological processes and of the factory equipment, and will also help them to specify and configure the data sources. The output of the tool will be used for configuring the micro-services in the C4IP platform.

Milestones and results

Milestone	Description	Month	Deliverable
M2.3.1	Specification of semantic data models for production resources and recipes	M12	Report
M2.3.2	Publication on semantic data models for manufacturing submitted	M15	Conference paper
M2.3.3	First implementation of the semantic data models for production resources	M18	Software development (module)
M2.3.4	First implementation of the semantic data models for production recipes	M21	Software development (module)
M2.3.5	Tool for creation and maintenance of the semantic released	M24	Software development (module)
M2.3.6	Publication on implementation of semantic data models for manufacturing submitted	M27	Journal publication
M2.3.7	Data transformation engine released	M30	Software development (module)
M2.3.8	Publication on the data transformation engine submitted	M32	Conference paper
M2.3.9	Extended version of the semantic data models for production resources released	M36	Software development (module)
M2.3.10	Final version of the semantic data models for production resources released	M50	Software development (module)
M2.3.11	Summarizing publication on semantic models for manufacturing submitted	M51	Journal publication

T2.4: Service Creation and Implementation

To create new services for the Cluster 4.0 Integration Platform and get it working as easy as possible, appropriate tooling is required. One suitable starting point for the establishment of a tool suitable for the definition and implementation of new services is 4DIAC. 4DIAC constitutes an implementation of IEC 61499 (a successor of IEC 61131-3; PLC programming languages) for distributed control applications. It consists of a run-time environment running on various kinds of devices, e.g., PLCs, Raspberry Pi, BeagleBone Black, and so on. In addition, 4DIAC provides an Eclipse-based IDE for the development of distributed control applications. Since 4DIAC has been proven as a suitable platform for industry and research and it is an official open source project within the IoT program of Eclipse, it is well suited for the integration and development of applications for the C4IP service architecture.
Thus, the decision will be taken if 4DIAC is going to be extended with C4IP concepts to support the creation and implementation of C4IP production control micro-services, which use IEC 61499 as a technology for real-time control. The reliance on IEC 61499 helps to ensure a broader acceptance of the developed Cluster 4.0

Integration Platform. A thorough research of possible solutions compared to 4DIAC will serve as a basis for the final decision.
An inherent part of this task is to develop a method for automated generating control code of components encapsulated within a single micro service. The method will use a library of control code implemented e.g. in IEC 61131 or IEC 61499 standard and knowledge about the topology and physical layout of the machines to generate a customized control code for a specific system configuration. This component will be used to cross the gap between the high-level semantic services used for orchestration of the whole system and the low-level control of physical production machines.

Milestones and results

Milestone	Description	Month	Deliverable
M2.4.1	Requirement specification of the service creation tool	M12	Report
M2.4.2	Publication on supportive tools for flexible manufacturing submitted	M15	Journal publication
M2.4.3	First version of the service creation tool released	M24	Software development (module)
M2.4.4	Publication on the service creation submitted	M27	Journal publication
M2.4.5	Code generation tool implemented as a standalone application	M30	Software development (module)
M2.4.6	Publication on code generation submitted	M33	Conference paper
M2.4.7	Integrated version of the service creation and code generation tools released	M36	Software – Beta version
M2.4.8	Publication on integration of service creation and code generation submitted	M40	Journal publication
M2.4.9	Final version of the development tool released	M47	Software

5.4.3.WP3: System Design

The work package is divided into several tasks focusing on methods of production specification based on domain ontologies, production line design stemming from the production specification, and simulations allowing to evaluate different production scenarios and check for their executability, reliability and profitability. This project does not deal with the product design, but its intention is to describe the product qualities in terms of ontologies that can be further utilised to match the product with its production, i.e. to express the requirements on the production in terms of semantic expressions.

A key issue is to link the methods with the system architecture and to utilize to proposed service-oriented model of execution and component interactions.

T3.1: Methods

A mechanism for semantic description of production resources will be designed. Each resource (such as a machine or a manufacturing cell) must be described in terms of offered operations and their parameters. The composition of manufacturing resources (e.g., manufacturing cells composed of multiple machines) will also be supported. In this case the compound operation is internally described as a workflow of atomic operations. We are going to consider semantic extensions of service description languages such as SAWSDL that will be utilized by given micro-services registered in C4IP. The workflows, i.e. production recipes, will also be described by semantic-based abstract descriptions. Attention will be paid mainly to discrete production (series of separate production steps). The description contains the type of requested manufacturing operations (to be matched with the services representing the manufacturing resources), including format of input and output parameters. The task will develop methods to semantically augment existing orchestration descriptions such as BPMN.

Furthermore, a generic production control ontology and a set of extending domain specific ontologies covering the specifics of the use cases will be created. They will rely on the use of OWL and RDF technologies and the process descriptions will be used and executed by the Orchestrator service of C4IP.

To keep the link between existing production technologies and the proposed ontologies for them to cover the existing behaviour, ontology engineering methods will be used to derive the ontologies semi-automatically from available process data (process mining). This will help us intercept the existing knowledge of industrial engineers, which is demonstrated by a working production line.

An ontology will be defined for each specific manufacturing domain within the project. We will concentrate on having the ontologies modular, i.e. some of their sections will be shared among different domains.

Milestones and results

Milestone	Description	Month	Deliverable
M3.1.1	Research of existing methodologies for project description	M3	Report
M3.1.2	Selection of manufacturing domains with respect to process description and ontologies from WP2	M6	Report
M3.1.3	Ontology design for the selected domains	M12	Conference paper
M3.1.4	Semantic product modelling	M30	Report
M3.1.5	Ontology engineering from process data	M36	Journal publication
M3.1.6	Mapping of product and production ontologies	M48	Journal publication

T3.2: Production line design

The flow of the material through the production defines the interfaces between individual workstations. This connects the product ontology with the production ontology. The objective of this task is to utilize the results of T3.1 to describe the production process at different levels, i.e. at the level of the production line, at the level of the individual workstations (manufacturing cells) and at the level of the components in the workstations. We are also going to focus on the layout design with respect to different space and functional constraints, communication capabilities and interfaces, and availability of the required material.

Milestones and results

Milestone	Description	Month	Deliverable
M3.2.1	Production line specification, material flow	M12	Report
M3.2.2	Mapping to production cell interfaces	M18	Journal publication
M3.2.3	Automation component ontology	M24	Conference paper
M3.2.4	Production cell ontology	M36	Conference paper
M3.2.5	Automatic creation of specification	M48	Journal publication

T3.3: Simulations

Industry 4.0 brings a new generation of production systems that are becoming more software-intensive. They are of a cyber-physical nature frequently, i.e., these systems consist of coupled software and hardware parts. Such cyber-physical production systems (CPPS) are becoming very complex and their engineering and testing are very complicated and time-consuming tasks, because the verification cannot be conducted component by component, but the whole ecosystem of interacting components must be tested at once. Only such approach can reveal unintended side effects caused by emergent behavioural patterns. Thus, shifting testing and tuning of industrial plants and their automation systems from the real world to simulated environments is a part of a “virtualization”, which is one of the key movements in emerging areas of Industry 4.0 and factories of the future.

In the field of the simulation model design, especially a component-based approach for simulation model creation will be addressed. It assumes that engineering systems consist of atomic components, which are connected into a real plant. The methodology that will be developed will support assembling of simulation models from the basic components.

The purpose of the simulations is to verify the production line design at all levels as created in T3.2. Due to one-to-one link with real equipment (supposed to be installed) in the plant the simulation models can be transformed and evaluated at the real equipment easily. It will also be possible to design and simulate the production iteratively and thus check various scenarios and optimization criteria and check for executability of the production plan. This is especially important in case of distributed real-time control based on agent negotiations. Such a negotiated production scenario will be simulated to see that all important performance and quality indicators are met as expected.

Milestones and results

Milestone	Description	Project month	Deliverable
M3.3.1	Simulation of production lines, iterative approach to scenario generation and specification checking	M18	Conference paper
M3.3.2	Simulation of the production cells, automatic generation of the simulation models	M36	Journal publication
M3.3.3	Feasibility and performance checking	M48	Journal publication
M3.3.4	Final evaluation	M51	Report

T3.4 Optimization of production processes

The growing complexity of production lines requires optimization algorithms able to harmonize production process and thus improve their efficiency. Based on the semantic description of production resources from T3.1, we will develop new methods to optimize the production process with respect to the flexibility. This task will focus on two important key performance indicators in production: (i) traditional aspects like production cycle time or lead time as well as (ii) efficient use of consumable resources like energy. In the first place, we will design exact optimization algorithms. This part involves (i) study of fundamental problem properties, (ii) design of decomposition approaches, e.g. branch-and-price, (iii) development of tight tailor-made lower bounds that can be efficiently solved, e.g. by special simplex methods. The fundamental problem properties and parts of exact algorithms will be subsequently used to construct heuristic solution able to solve large industrial problems. Thus, the second part includes (i) design of highly efficient algorithms, (ii) research of efficient solution space exploration mechanisms and (iii) parallelization of algorithms using parallel accelerators like a GPGPU or Intel Xeon Phi.

Milestones and results

Milestone	Description	Project month	Deliverable
M3.4.1	Research on optimization problems and algorithms for production process	M6	Report
M3.4.2	Study on the fundamental problem properties	M12	Conference paper
M3.4.3	Design and decompossition approaches	M24	Conference paper
M3.4.4	Solution of production problém optimization by exact approaches	M36	Journal publication
M3.4.5	Efficient solution for large problém instances	M48	Conference paper
M3.4.6	Parallel algorithms for optimization of production process	M51	Journal publication

5.4.4.Schedule and deliverables

In this section a summary list of deliverables is provided. It contains journal papers (JP) that are also counted as project indicators in section 5.5, and conference papers (CP). The table contains the number of the milestones that also relates the deliverable to a task, description and the project month in which the output is to be delivered.

Milestone	Description	Month	Deliv.
M1.1.3	Definition of the Testbed use case together with the design KPIs	M12	JP
M1.2.2	Integration of the flexibility measure into the Testbed use case	M12	CP
M3.1.3	Ontology design for the selected domains	M12	CP
M3.4.2	Study on the fundamental problem properties	M12	CP
M2.3.2	Publication on semantic data models for manufacturing submitted	M15	CP
M2.4.2	Publication on suportive tools for fexible manufacturing submitted	M15	JP
M2.2.3	A publication on service oriented manufacturing submitted	M18	CP
M3.2.2	Mapping to production cell interfaces	M18	JP
M3.3.1	Simulation of production lines, iterative approach to scenario generation and specification checking	M18	CP
M1.1.4	Implementation of the first prototype of C4IP in Testbed.	M24	JP
M1.2.3	Generalization of the flexibility measures	M24	CP
M3.2.3	Automation component ontology	M24	CP
M3.4.3	Design and decompossition approaches	M24	CP
M2.3.6	Publication on implementation of semantic data models for manufacturing submitted	M27	JP
M2.4.4	Publication on the service creation submitted	M27	JP
M2.2.5	A publication on results of the developed service-oriented manufacturing system submitted	M30	JP
M2.3.8	Publication on the data transformation engine submitted	M32	CP
M1.2.4	Integration of the flexibility measures into the industrial use cases from T1.1	M33	CP
M2.4.6	Publication on code generation submitted	M33	CP
M3.1.5	Ontology engineering from process data	M36	JP
M3.2.4	Production cell ontology	M36	CP
M3.3.2	Simulation of the production cells, automatic generation of the simulation models	M36	JP
M3.4.4	Solution of production problém optimization by exact approaches	M36	JP
M2.4.8	Publication on integration of service creation and code generation submitted	M40	JP
M1.1.7	Implementation of the industrial use cases	M45	CP
M2.1.4	Final version of the Cluster 4.0 Integration Platform implemented	M48	CP

M3.1.6	Mapping of product and production ontologies	M48	JP
M3.2.5	Automatic creation of specification	M48	JP
M3.3.3	Feasibility and performance checking	M48	JP
M3.4.5	Efficient solution for large problém instances	M48	CP
M1.1.8	Evaluation of the industrial use cases and their KPIs	M51	JP
M1.2.5	Evaluation of the flexibility measures	M51	JP
M1.3.4	Evaluation of the process and indicators finished	M51	JP
M2.3.11	Summarizing publication on semantic models for manufacturing submitted	M51	JP
M3.4.6	Parallel algorithms for optimization of production process	M51	JP

5.5. Research outputs and results

In the following overview the total number of project indicators is presented. The publications are described in more details in the previous sections. The international patent (2 20 11) is expected to be submitted after 24 months of the project. Software is going to be open and this result will be based on the partial results (software tools) described as milestones in WP2 and WP3.

Results and outputs of the activity	Target value for project implementation
Indicator: 2 02 11 Professional publications (selected types of documents) created by supported entities Link to the research objectives WP1, WP2, WP3 within Chap. 5 Feasibility study	18
Indicator: 2 02 13 Professional publications (selected types of documents) co-authored by research organisations and enterprises Link to the research objectives WP1, WP2, WP3 within Chap. 5 Feasibility study	4
Indicator: 2 02 16 Professional publications (selected types of documents) with foreign co-authors created by supported entities Link to the research objectives WP1, WP2, WP3 within Chap. 5 Feasibility study	8
Indicator: 2 20 11 International patent applications (PCT) created by supported entities Link to the research objectives WP1, WP2, WP3 within Chap. 5 Feasibility study	1
Another result: Software for non-commercial use developed within the project Link to the research objectives WP1, WP2, WP3 within Chap. 5 Feasibility study	1

Intellectual property treatment

As an indispensable part of the implementation of research activities and for successful cooperation of several entities with partial interests it is necessary to treat the issue of intellectual property and know-how. All project partners are already working on this issue in their product development projects as well as in applied research projects. This experience and practice also set up the framework that will be applied in the Cluster 4.0 project.

The partners enter the project with skills, know-how and other intellectual property rights that are needed to implement the project. The knowledge inserted remains the property of the partners who put them into the project. Other partners are allowed to use the knowledge for project work, if necessary, for the project duration.

Owners of results are required to design and implement appropriate intellectual property protection embodied in the results achieved, such as confidentiality of the results information, or copyright protection, if applicable. The protection of intellectual property consists mainly in the submission of domestic and / or foreign applications for technical solutions or copyright protection.

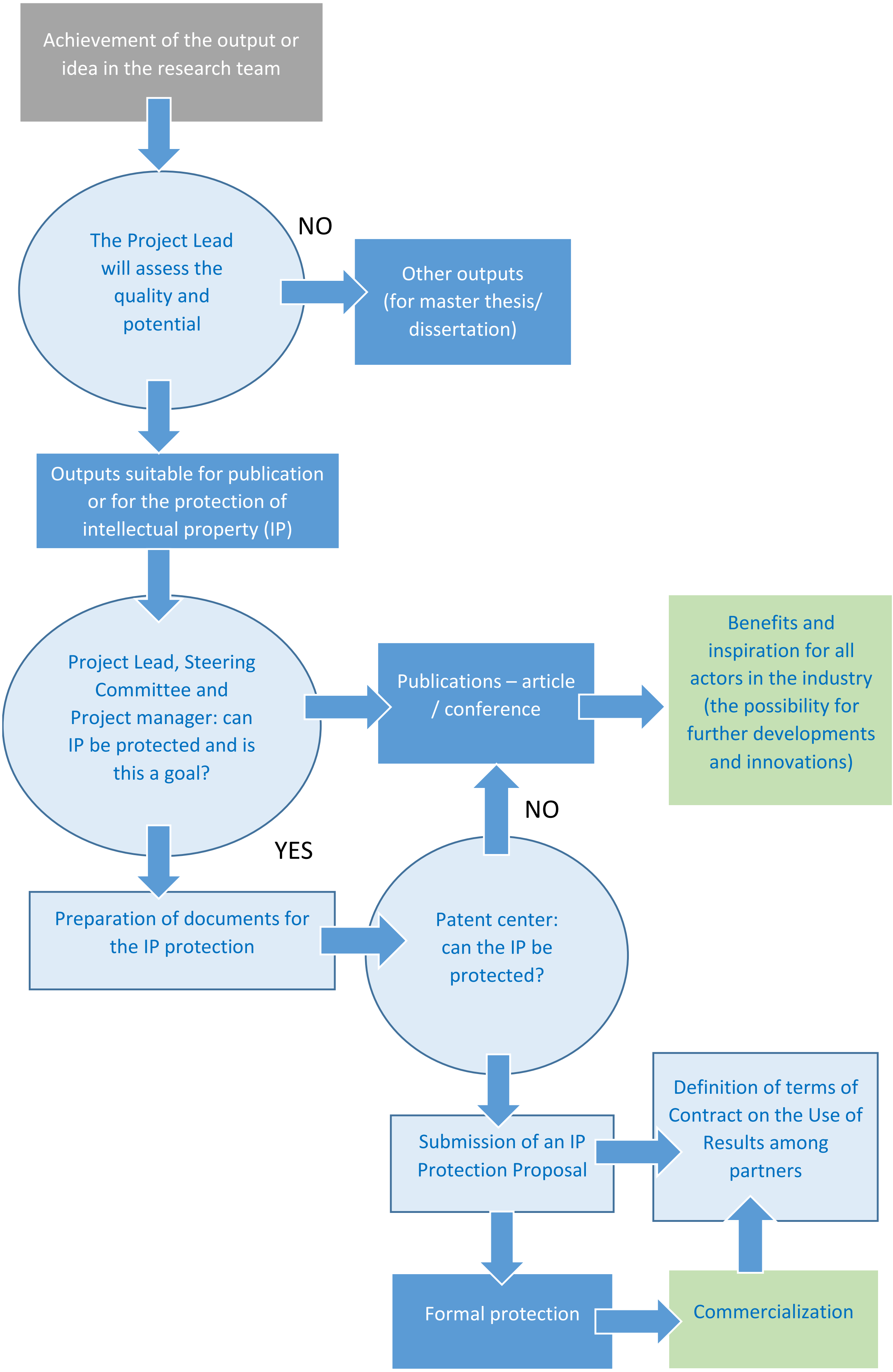
If the result is owned jointly by the partners, they file an application for protection jointly so that the partners become co-owners of the relevant institute of protection. For relations between partners as the co-owners of the relevant subject of industrial property rights, the provisions of generally binding legal regulations regulating co-ownership are applied and will be described in detail in the partnership agreement.

At present, the applicant disposes model templates dealing with the issue of intellectual property rights arising in cooperation with businesses. The rights and obligations of the parties are set to be in line with national and European legislation and to prevent unauthorized public support. The Applicant is aware of, and will be guided by, the content and obligations arising from the established legislation (Act No. 130/2002 Coll., On Support of Research and Development, Act No. 218/2000 Coll., On Budgetary Rules and on Amendments to Certain Related Acts (Commission Regulation (EU) No 651/2014 of 17 June 2014 declaring certain categories of aid compatible with the internal market in accordance with Articles 107 and 108 of the Treaty - Official Journal of the European Union L 187/26 (hereinafter referred to as "the Regulation"), in particular Articles 25, 28 and 29; Framework for State Aid for Research, Development and Innovation - Official Journal of the European Union C 198 of 27 June 2014).

For the conclusion of contracts, internal processes and guidelines are in place for the applicant to ensure that the content of a particular contract is correct. This model of contracting is already standardized and is commonly used in the organization, therefore, it is expected that there will be no breach of the legislative requirements in the area of public support.

The model will be used to address the issues related to intellectual property rights created by the project partners. In chapter 5 of the feasibility study, further treatment of intellectual property is not described in greater detail.

A plan for the protection of intellectual property is prepared for research activities, which will lead to the protection of the acquired knowledge and results. Since partners are also involved in the project, the Contracts on the use of results will need to be addressed. The plan for the process of preparing the protection of intellectual property is shown in the following diagram, which describes the scheme of dealing with newly created intellectual property, ideas and inspiration.


Achievement of the output or idea in the research team
The Project Lead will assess the quality and potential
NO
Other outputs (for master thesis/ dissertation)
Outputs suitable for publication or for the protection of intellectual property (IP)
Project Lead, Steering Committee and Project manager: can IP be protected and is this a goal?
Publications – article / conference
Benefits and inspiration for all actors in the industry (the possibility for further developments and innovations)
NO
YES
Preparation of documents for the IP protection
Patent center: can the IP be protected?
Submission of an IP Protection Proposal
Definition of terms of Contract on the Use of Results among partners
Formal protection
Commercialization

5.6. Research team

The research team is composed members that have long term experience in applied research based on solid theoretical results. It consists of excellent researchers with strong publication record (Vladimir Mařík, Zdeněk Hanzálek), who are going to supervise the research from the point of view of its novelty and publication potential. It complies with the Cluster 4.0 team forming strategy and promises achieving scientific results with a solid publication potential in impacted journals.

Project leader Pavel Burget and work package leaders Petr Kadera, Petr Kolář and Tilman Becker have lead or participated in many projects of applied research and industrial-grade contracts. Their role (no matter the average publication track record) is irreplaceable due to their excellent experience with industrial collaboration and projects. The new team members, who have not been hired yet, are going to comply with this strategy as well, i.e. they are supposed to have a good publication record an application potential. Such a combination of research and application potential forms background necessary to achieve the expected results with industrial potential.

The team has got vast experience in design and development of the SOA based industrial solutions in the field of production scheduling and planning within the frame of the EU projects WP 7 - ARUM and DIGICOR (H2020) delivering useful solutions to the Airbus Group. In the field of production technology and machining there is a strong link of the team to prestigious Research Center of Manufacturing Technology (RCMT), which provides the knowledge necessary for the technology of the production processes. The team experience might be explored in delivering new original architectures and solutions needed in the current Czech SMEs as well as for the needs of global manufacturers in the automation domain.

Pavel Burget (Principal Investigator) leads Testbed for Industry 4.0 at CIIRC CTU. His research activities focus on the area of design and use of conventional and distributed control systems, manufacturing control and optimization, industrial communication analysis and diagnostics. He has been the leader of several application-oriented research projects and industrial contracts in intelligent manufacturing. He is Certified Competency and Training Centre member of the PROFINET working group within PROFIBUS & PROFINET International (PI), and the editor of several PROFINET guidelines used by technology providers and device manufacturers over the world. He is responsible for the activities of the accredited by PI. Dr. Burget published several journal articles in prestigious journals like IEEE Transactions on Industrial Informatics or IEEE Control Engineering Practice.

- Petr Kadera (Work package leader)
- Tilman Becker (Deputy project lead, Work package leader)
- Vladimír Mařík (excellent researcher)
- Zdeněk Hanzálek (excellent researcher)

Structured CVs of the members of the research team including their research profiles are documented in Annex 8 CVs of the research team members - Applicant and Annex 24 CVs of the research team members - Partner.

Team structure, roles, research activities and recruitment schedule

A table describing the expert team members' roles and degree of involvement. Indicate both filled and open positions. Position name must match the position indicated in the detailed budget, i.e. there must be a clear link to the items of the detailed budget.

First and last name (for open positions please indicate "to be nominated")	Employer (applicant, project partner)	H-index (named members)	Type - excellent - key - ordinary member	Position in the team (leader, researcher, technician, ...)	FTE dur… years in…	
					2017	
Pavel Burget	applicant	3 (WOS)	key	PI - key	0	0
Vladimír Mařík	applicant	16 (WOS)	excellent	senior researcher - excellent	0	0
Zdeněk Hanzálek	applicant	11 (WOS)	excellent	senior researcher - excellent	0	0
Petr Kolář	applicant	2 (WOS)	key	WP leader - key	0	0
Petr Kadera	applicant	3 (WOS)	key	WP leader - key	0	0
Jiří Švéda	applicant	1 (WOS)	key	senior researcher - key	0	0
to be nominated	applicant		ordinary	junior	0	0
to be nominated	applicant		ordinary	junior	0	0
to be nominated	applicant		ordinary	technician - engineer	0	0
to be nominated	applicant		ordinary	PostDoc	0	1
to be nominated	applicant		ordinary	junior	0	1
to be nominated	applicant		ordinary	junior	0	0
to be nominated	applicant		ordinary	technician - programmer	0	1
to be nominated	applicant		ordinary	PostDoc	0	1
to be nominated	applicant		ordinary	junior	0	1
Tilman Becker	project partner	1 (WOS)/18 (Google Scholar)	key	deputy project lead	0	0
to be nominated	project partner		key	WP leader – key	0	0
to be nominated	project partner		key	senior researcher – key	0	0

Qualification prerequisites for open positions. Indicate for positions you plan to fill with excellent, key and leading staff members.	
Staff member position	**Qualification prerequisites**
WP leader	• a staff member with a Ph.D. degree (or an equivalent or a CSc. scientific degree), a high performer in terms of publications focusing on periodicals with an impact factor or applied results • experience of collaboration with the application sector (demonstrable participation in projects of contract or collaborative research) • experience in leading research teams and has been an investigator of major grant projects • Proficiency in English (written and spoken)
Senior Researcher	• a staff member with a Ph.D. degree (or an equivalent or a CSc. scientific degree) • previous publication • experience of collaboration with the application sector (demonstrable participation in projects of contract or collaborative research) • experience in leading research teams and has been an investigator of major grant projects • Proficiency in English (written and spoken)

Results and outputs of the activity	Target value for project implementation
Indicator: CO 24 / 2 04 00 Number of new researchers in supported entities Link to the research objectives WP1, WP2, WP3 within the Chap. 5 Feasibility study	5.3
Indicator 2 04 02 Number of new researchers in supported entities – women Link to the research objectives WP1, WP2, WP3 within the Chap. 5 Feasibility study	1

Key achievements of the key and excellent members of the expert team for the past 5 years

Vladimír Mařík, H-index acc. WOS = 16

5 most significant results in terms of scientific publications for the period 2012–2016:

- Strassen, T. - Andrén, F. - Kathan, J. - Cecati, C. - Buccella, C. - et al.: A Review of Architectures and Concepts for Intelligence in Future Electric Energy Systems. IEEE Transactions on Industrial Electronics. 2014, vol. PP, no. 99, art. no. 1. **IF 8,785**. Number of citations. 66
- Leitao, P. - Mařík, V. - Vrba, P.: Past, Present, and Future of Industrial Agent Applications. Industrial Informatics, IEEE Transactions on Industrial Informatics. 2012, vol. 8, no. 5, p. 1-12. ISSN 1551-3203. **IF 3,381**. Number of citations. 54
- Vrba, P. - Mařík, V. - Siano, P. - Leitão, P. - Zhabelova, G. - et al.: A Review of Agent and Service-Oriented Concepts Applied to Intelligent Energy Systems. Industrial Informatics, IEEE Transactions on. 2014, vol. 10, no. 3, p. 1890-1903. ISSN 1551- 3203. **IF 8,785**. Number of citations. 44
- Jirkovský, V. – Obitko, M. – Mařík, V.: Understanding Data Heterogeneity in the Context of Cyber-Physical Systems Integration. IEEE Transactions on Industrial Informatics on. 2017, vol. 13, no. 2, p. 660-667, doi: 10.1109/TII.2016.2596101 **IF 4,708**. Number of citations. 1
- Tupa, O.; Procházka, A.; Vyšata, O.; Schatz, M.; Mareš, J.; Valis, M.; Mařík, V. Motion Tracking and Gait Feature Estimation for Recognising Parkinson's Disease Using MS Kinect Biomedical Engineering Online. 2015, 14 ISSN 1475-925X. **IF 1,683**. Number of citation. 8

5 most significant results in terms of obtaining grant resources:

- Grant name: Control and decision-making in industrial production I-III
  Funding Source: Research intention of the Ministry of Education, Youth and Sports
  From – to: 1999 - 2011
  Grant award: 16 000 000 EUR
  Project position: Scientific and financial coordinator
- Grant name: EU Centrum excellence MIRACLE
  Funding Source: EU project
  From – to: 2000 - 2007
  Grant award: 30 million CZK
  Project position: Project Leader
- Grant name: EU integrated project ARUM „Adaptive Production Management“
  Funding Source: EU project 7. RP
  From – to: 2012 - 2015
  Grant award: 270 million CZK
  Project position: Project technical director
- Grant name: CIIRC CTU
  Funding Source: Ministry of Education, Youth and Sports, Czech Republic, state budget
  From – to: 2014-2016
  Grant award: 52 000 000 EUR
  Project position: Principal investigator

- Grant name Decentralised Agile Coordination Across Supply Chains
  Funding Source Horizon 2020
  From – to 2016 - 2019
  Grant award 469 000 EUR
  Project position Principal investigator

5 most significant results in terms of patents and collaboration with industry:

- Šišlak, D. - Pěchouček, M. - Volf, P. - Mařik, V. - Losiewicz, P.: System and Method for Planning/Replanning Collision Free Flight Plans in Real or Accelerated Time. Patent United States Patent and Trademark Office (USPTO), US8,538,673. 2013-09-17.
- Vrba, P. – Hall, K.H. – Kadera, P. – Mařik, V. – Obitko, M. – Radakovič, M.: Ontologybased System and Method for Industrial Control. Patent United States Patent and Trademark Office (USPTO), US8, 145, 333. 2012-03-27.
- Maturana, F. P. - Hall, K.H. - Staron, R.J. - Šlechta, P. - Mařik, V. - et al.: Agent- Equipped Controller Having Data Table Interface between Agent-type Programming and Non-Agent-Type Programming. Patent United States Patent and Trademark Office (USPTO), US7,640,291. 2009-12-29.
- Vrba, P. - Macurek, F. - Mařik, V. - Hall, K. - Tichy, P.: Systems and Methods that Integrate Radio Frequency Identification (RFID) Technology with Agent-Based Control Systems. Patent United States Patent and Trademark Office (USPTO), US7, 551,081. 2009-06-23.
- Tichy, P. - Maturana, F. - Hall, K. H. - Staron, R. - Šlechta, P. – Mařik, V.: System and Method for Interfacing Multi-agent System.

Zdeněk Hanzálek, H-index acc. WOS = 11

5 most significant results in terms of scientific publications for the period 2012–2016:

- TRDLICKA, JIRI; HANZALEK, ZDENEK. , In-Network Distributed Algorithm for Energy Optimal Routing Based on Dual Decomposition of Linear Programming. IEEE TRANSACTIONS ON COMMUNICATIONS. 2012, 60 (6), 1634-3645. **IF 4,058**. Number of citation. 8
- ČAPEK, R., ŠŮCHA, P., HANZÁLEK, Z. Production Scheduling with Alternative Process Plans. European Journal of Operational Research. 2012, 217(2), 300-311. **IF 2.038**. Number of citations: 8
- HANZÁLEK, Z., TUNYS T., ŠŮCHA, P. An Analysis of the Non-preemptive Mixed-criticality Match-up Scheduling Problem. Journal of Scheduling. 2016, 19(5), 601–607. **IF 1,281**. Number of citations: 3
- BÄUMELT, Z., ŠŮCHA, P., HANZÁLEK, Z. A Multistage Approach for an Employee Timetabling Problem with a High Diversity of Shifts as a Solution for a Strongly Varying Workforce Demand. Computers & Operations RAI&Reasoning: Artificial Intelligence and Reasoningesearch. 2014, 49, 117-129. **IF 1.861**. Number of citations: 2.
- MÓDOS, I., ŠŮCHA, P., VÁCLAVÍK, R., SMEJKAL, J., HANZÁLEK, Z. Adaptive online scheduling of tasks with anytime property on heterogeneous resources. Computers and Operations Research. 2016, 76, 95–117. **IF 2.600**. Number of citations: 0

5 most significant results in terms of obtaining grant resources:

- Grant name High-Performance Embedded Real-time Architectures for Low-Power Many-Core Systems - Autonomous Car Driving Use-case
  Funding Source Horizon2020, European Commission 688860
  From– to 2015 – 2018
- Grant name AI&Reasoning: Artificial Intelligence and Reasoning
  Funding Source Excellent Research Teams within the Operational Programme Research, Development, and Education and the Czech Ministry of Education
  From– to 2016 – 2022
- Grant name Component-oriented Design Methodology for Safety and Security modelling
  Funding Source FP7 EU 295354
  From– to 2012 – 2015
- Grant name Framework for Real-time Embedded Systems based on COntRacts
  Funding Source FP6 IST-034026
  From– to 2006 – 2009
- Grant name Design, Monitoring and Operation of Adaptive Networked Embedded Systems
  Funding Source FP7 EU 295372
  From– to 2012 – 2015

5 most significant results in terms of patents and collaboration with industry:

- Volkswagen, Wolfsburg, Germany (2010 – 2015). We realized series of contracts (186000,- EURO) on Linux based CAN gateway and IEEE 802.11p wireless networks used in Car-to-Car communication.
- Contracts with Porsche Engineering Services Prague (160000,- EURO), (2016 – present), Autonomous driving – path planning and high performance computing.
- Contracts with EATON Prague (120000,- EURO), (2014 – present), Factory of Future – rescheduling algorithms.
- Personnel Scheduling for Air Navigation Services of the Czech Republic via Merica
- Profibus FDL Master for European Train Control System - commercialized via AZD to Czech Railways (Implementation of Train Communication Network - commercialized via UniControls Ltd. to Alstom)

<u>Pavel Burget, H-index acc. WOS = 3</u>

5 most significant results in terms of scientific publications for the period 2012–2016:

- Ron, M.; Burget, P.; Fiala, O. Identification of Operations at Robotic Welding Lines. In: Proceedings of the IEEE International Conference on Automation Science and Engineering. Piscataway: IEEE, 2015. pp. 470-476. ISSN 2161-8070. ISBN 978-1-4673-8183-3. Number of citations: 2
- Bukata, Libor; Sucha, Premysl; Hanzalek, Zdenek; et al. Energy Optimization of Robotic Cells. IEEE TRANSACTIONS ON INDUSTRIAL INFORMATICS. 2017, 13(1), 92-102. **IF 6,764**. Number of

citations: 0

- Fencl, T., Burget, P., Bílek, J. Network topology design In Control Engineering Practice, vol. 19, no. 11, p. 1287-1296. ISSN0967-0661. **IF 2,291**. Number of citations: 0
- Hanzálek, Z., Burget, P., Šůcha, P. Profinet IO IRT Message Scheduling With Temporal Constraints In IEEE Transactions on Industrial Informatics, 2010, vol.6, no.3,p.369-380.ISSN1551-3203. **IF 6,764**. Number of citations: 30
- Ron, M.; Burget, P. Stochastic modelling and identification of industrial robots. In: Proceedings of the IEEE International Conference on Automation Science and Engineering. Piscataway, NJ: IEEE, 2016. pp. 342-347. ISSN 2161-8070. ISBN 978-1-5090-2409-4.

5 most significant results in terms of obtaining grant resources:

- Grant name Environment for distant and on-line multimedia education
  Funding Source Ministry of Education of the Czech Republic
  From– to 2006 – 2009
  Grant award 31 mil. CZK
- Grant name Building automation. Developing prototype tools allowing to achieve energetic savings without additional investments in the instrumentation or building adaptations
  Funding Source Ministry of Industry and Trade of the Czech Republic
  From – to 2006 – 2011
  Grant award 45.5 mil. CZK
- Grant name System Management in diverse real-time Automation networks (SMartA)
  Funding Source EraSME European programme
  From – to 2013-15
  Grant award 0.8 mil. CZK
- Grant name Automatic verification of production lines properties during virtual commissioning
  Funding Source Czech Ministry of Industry and Trade
  From – to 2016-18
  Grant award 6.6 mil. CZK
- Grant name Integration of the systems in the buildings, research and application of intelligent algorithms that have influence on the energy consumption
  Funding Source Czech Ministry of Industry and Trade
  From – to 2006-11
  Grant award 21.5 mil CZK

5 most significant results in terms of patents and collaboration with industry:

- Optimisation of energy consumption in car-body welding lines. Contract with Skoda Auto. 2.9 mil. CZK, 2013-2015
- Design and development of tool IRTcheck. Contract with Profibus Nutzerorganisation e.V. (PNO). Budget 0.5 mil. CZK, 2014
- Numerous courses on industrial communications (Profibus, Profinet) for industry. 2.5 mil CZK, 2009-2017
- Optimization of energy consumption on robotic lines (2016), Semi-operation, proven technology
- *IRTCHECK: a tool for checking the parameters of profinet irt message schedules (2015),

software

Petr Kadera, H-index acc. WOS = 3

5 most significant results in terms of scientific publications for the period 2012–2016:

- Tichý, P., Kadera, P., Staron, R. J., Vrba, P., Mařík, V. Multi-agent System Design and Integration via Agent Development Environment. In Engineering Applications of Artificial Intelligence, Vol. 25, Issue 4, 2012, pp. 846-852. **IF 2,894.** Number of citations: 5
- Novák, P., Kadera, P., Jirkovský, V., Vrba, P., Biffl, S. Engineering of Coupled Simulation Models for Mechatronic Systems. In proceedings of the International Workshop on Service Orientation in Holonic and Multi-Agent Manufacturing, 2014. Number of citations: 1
- Jirkovský, V., Obitko, M., Novák, P., Kadera, P. Big Data Analysis for Sensor Time-Series in Automation. In proceedings of the 19th IEEE International Conference on Emerging Technologies and Factory Automation, 2014. Number of citations: 0
- Kadera P., Macaš M. Applying Agents and Genetic Algorithms for Reducing Peak Consumption in District Heating. In Industrial Applications of Holonic and Multi-Agent Systems, Springer International Publishing, 2015. Number of citations: 0
- Kadera, P., Novák, P. Performance Modeling Extension of Directory Facilitator for Enhancing Communication in FIPA-Compliant Multiagent Systems. IEEE Transactions on Industrial Informatics, Vol. 13, Issue 2, 2017, pp. 688-695**. IF 6,764.** Number of citations: 1

5 most significant results in terms of obtaining grant resources:

- Grant name KnowDrift: Knowledge-Driven Industrial Robotics for Flexible Production
  Funding Source Die Österreichische Forschungsförderungsgesellschaft mbH (FFG)
  From– to 2017 - 2019
- Grant name DIGICOR: Decentralised Agile Coordination Across Supply Chains
  Funding Source H2020
  From – to 2016 - 2019
- Grant name Enabling research organizations to join the European Energy Research Alliance
  Funding Source The Ministry of Education, Youth and Sports of the Czech Republic
  From – to 2016 - 2017

5 most significant results in terms of patents and collaboration with industry:

- Vrba, P., Hall, K. H., Kadera, P., Mařík, V., Obitko, M., Radakovic, M. U.S. Patent No. 8,145,333. Washington, DC: U.S. Patent and Trademark Office, 2012.
- Obitko, M., Vrba, P., Kadera, P., Jirkovský, V. U.S. Patent No. 20,130,055,115. Washington, DC: U.S. Patent and Trademark Office, 2013.
- Cooperation with the Research and development laboratory of Rockwell Automation Company.
- Cooperation with Airbus on utilization of agent-based approaches for scheduling in complex manufacturing.

<u>Petr Kolář, H-index acc. WOS = 2</u>

5 most significant results in terms of scientific publications for the period 2012–2016:

- Kolář P, Fojtu P, Schmitz T, On Cutting Force Coefficient Model with Respect to Tool Geometry and Tool Wear. Procedia Manufacturing, Vol 1, 2015, Pages 708–720. 43rd North American Manufacturing Research Conference, NAMRC 43, pp. 8-12, June 2015, UNC Charlotte, North Carolina, United States.
- Kolář P, Mašek P, Zeman P, Milling Tools for Cutting of Fibre-reinforced Plastics. Journal of Machine Engineering, Vol. 14, No. 2, 2014, ISSN 1426-708X
- Mašek, P., Zeman, P., Kolář, P.: Development of a cutting tool for composites with thermoplastic matrix. MM Science Journal, October 2013, pp. 422-427, DOI: 10.17973/MMSJ.2013_10_201312
- Kolář, P., Mašek, J., Švéda, J., Hudec, J.: Influence of Machine Tool Covers on Feed Drives. In: ASME 2011 International Manufacturing Science and Engineering Conference. Corvallis: Oregon State University, 2011, p. 57-64. ISBN 978-0-7918-4431-1.
- Kolar, P., Sulitka, M., Janota, M.: Simulation of Dynamic Properties of a Spindle and Tool System coupled with a Machine Tool Frame In: The International Journal of Advanced Manufacturing Technology [online]. 2011, vol. 54, no. 1, p. 11-20. **IF 2,209.** Number of citations: 29

5 most significant results in terms of obtaining grant resources:

- Grant name — Integrated Process Chain for Automated and Flexible Production of Fibre-Reinforced Plastic Products (FIBRACHAIN).
  Funding Source — 7FP
  From – to — 2011-2014
  Grant award — Total budget of EUR 9 945 506, CTU budget of EUR 651 000
- Grant name — INTElligent FIXtures for the manufacturing of low rigidity components (INTEFIX)
  Funding Source — 7FP
  From – to — 2013-2015
  Grant award — Total budget of EUR 10 253 512, CTU budget of EUR 397 120
- Grant name — Productive machining of accurate workpieces
  Funding Source — Technology Agency of the Czech Republic within Alfa program
  From – to — 2012-2015
  Grant award — Total budget of CZK 36 436 000, CTU budget of CZK 11 768 000
- Grant name — Modelling of cutting forces and machining stability with respect to cutting edge wear
- Funding Source — Ministry of Education within KONTAKT II program
  From – to — 2012-2015
  Grant award — Total budget of CZK 3 612 000 (approx. EUR 133 700)

5 most significant results in terms of patents and collaboration with industry:

- Hovorka J., Kolář P.: Device for balancing of vertical linear moving axes of machine tools Patent. Czech Industrial Property Office, No. 303596. 2012-11-21

- Kolář P., Ondráček M., Houša J.: Surface Telescopis Covers Especially for Machine Tools. Patent. European Patent Office, EP1625913. 2007-10-10.
- Kolář, P., Hudec, J., Mašek, J.: Cover with compliant connection to the moving axis. Prototype. Applied in the practical applications.
- Kolář, P., Matyska, V., Fornůsek, T., Horejš, O., Hornych, J., Janota, M., Mareš, M., Moravec, J., Sulitka, M., Šindler, J., Sušeň, J., Šimůnek, A., Veselý, J., Zábranský, V., Zeman, P., Mindl. J., Kopal, M., Strnad, T., Šnajdr, K.: Inovated five-axis vertical machining centre MCU 700V - 5X PLUS. Prototype. Development of a key machine in the company portfolio.
- Kolář, P., Zeman, P., Mašek, P.: Diamond-coated milling tool for FRTC material. Prototype.

<u>Jiří Švéda, H-index acc. WOS = 1</u>

5 most significant results in terms of scientific publications for the period 2012–2016:

- Novotny L., Sindler J., Fiala S., Sveda J., Modelling and Optimization of Machine Tools on Foundations, In: Journal of Machine Engineering, 2016, vol. 16, no. 1, p. 43-56. ISSN 1895-7595.
- Koubek J., Chládek Š., Švéda J., Diviš I., Measurement of tool centre position change on horizontal boring machines, In: 15th International Conference and Exhibition of the European Society for Precision Engineering & Nanotechnology. Cranfield, Bedfordshire: euspen, 2015, p. 255-256. ISBN 978-0-9566790-7-9.
- Kolář P., Švéda J., Hudec J., Mašek J., Interaction of Machine Tool Cover and Feed Drive, In: Innovation in Machining 2012. Guipúzcoa: Centro Tecnológico Tekniker, 2012, p. 1-6. ISBN 978-84-932064-6-8.
- Kolář P., Mašek J., Švéda J., Hudec J., INFLUENCE OF MACHINE TOOL COVERS ON FEED DRIVES, In: ASME 2011 International Manufacturing Science and Engineering Conference. Corvallis: Oregon State University, 2011, p. 57-64. ISBN 978-0-7918-4431-1.
- Sveda, J., Valasek, M., Sika, Z., Simulation and experimental testing of machine tool active feed drive, In: Proceedings of the IASTED International Conference on Modelling and Simulation, MS 2009; ACTA Press; Calgary - Anaheim - Zürich; 2009, p. 17-23. ISSN: 1021-8181.

5 most significant results in terms of obtaining grant resources:

- Grant name Competence Centre - Engineering production technology, responsible person for workpackage WP09 New Measurement and Control Systems to increase accuracy and reliability
  Funding Source Ministry of Education of the Czech Republic
  From – to 2012 - 2019
  Grant award 317 984 tis. CZK
- Grant name INTEFIX – Intelligent fixtures for the manufacturing of low rigidity components, the person responsible for the work package WP11 Fixture system for workpiece adjustment and clamping with/without its pre-deformation
  Funding Source EU FP7
  From – to 2013 - 2016

Grant award 10 253 tis. EUR

- Grant name In-process measurement
  Funding Source Ministry of Industry and Trade of the Czech Republic
  From – to 2012 - 2014
  Grant award 24 450 tis. CZK
- Grant name New generation of control system for production machines
  Funding Source TA ČR
  From – to 2011 - 2013
  Grant award 30 700 tis. CZK
- Grant name Mechatronic concept of horizontal machines
  Funding Source Ministry of Industry and Trade of the Czech Republic
  From – to 2008 - 2010
  Grant award 87 974 thousands CZK

5 most significant results in terms of patents and collaboration with industry:

- Valášek, M., Švéda, J.: Device for reducing transmission of forces into the frame from two mutually acting parts, patent 304114. 2012-566. Commercially not used.
- Valášek M., Nečas M., Beneš P., Švéda J., Equipment for optical measurement and / or optical calibration of the position of the body in space, patent 304495. 2012-897. Commercially not used.
- Švéda J., Beneš P., Valašek, M., Šika Z., Koubek J., et al., Redundant measuring and calibration machine, Functional sample, CTU in Prague. 2015.
- Swede J., Hornych, T., Schut M., Machine tool prototype with newly opened MEFI control system, Prototype, CTU in Prague and MEFI, s.r.o., 2013.
- Švéda J., Diviš I., Devices for optical measuring of precision and / or deformation of a machine tool, Utility model, 21841. 2011-02-28.

Tilman Becker, H-index acc. WOS = 1

5 most significant results in terms of scientific publications for the period 2012–2016:

- Sonja Zillner; Tilman Becker; Ricard Munn; Kazim Hussain; Sebnem Rusitschka; Helen Lippell; Edward Curry; Adegboyega Ojo. Big Data-Driven Innovation in Industrial Sectors. In: Cavanillas J. M.; Edward Curry; Wahlster W. (Eds.). New Horizons for a Data-Driven Economy. Pages 143-165, ISBN 978-3-319-21568-6 (Print) 978-3-319-21569-3 (Onlin, Springer, Heidelberg, 2016.
- Tilman Becker, Edward Curry, Anja Jentzsch, Walter Palmetshofer. Cross-sectorial Requirements Analysis for Big Data Research in New Horizons for a Data-Driven Economy, Springer, 2016.
- Tilman Becker, Edward Curry, Anja Jentzsch, Walter Palmetshofer. New Horizons for a Data-Driven Economy: Roadmaps and Action Plans for Technology, Businesses, Policy, and Society in New Horizons for a Data-Driven Economy, Springer, 2016.
- Robert Neßelrath, Tilman Becker, Melanie Reiplinger, Tim Schwartz. SiAM-dp, eine multimodale Dialogplattform im Industriekontext in Intelligente Vernetzung in der Fabrik - Industrie 4.0 Umsetzungsbeispiele für die Praxis, Fraunhofer Verlag, 2015.

- Tilman Becker. Big Data Usage in New Horizons for a Data-Driven Economy, Springer, 2016.

5 most significant results in terms of obtaining grant resources:

- Grant name Augmented Multi-party Interaction
  Funding Source FP6-IST
  From 2003
  Grant award 8 800 000 EUR
- Grant name Talk and Look, Tools for Ambient Linguistic Knowledge
  Funding Source FP6-IST
  From 2003
  Grant award 4 395 000 EUR
- Grant name SMARTKOM
  Funding Source German Federal Ministry of Education and Research
  From - to 1999 - 2003
  Grant award 82 600 000 EUR
- Grant name Conversational Multimodal Interaction with Computers
  Funding Source FP5-IST
  From - to 2002-2005
  Grant award 4 357 674 EUR
- Grant name Verbmobil
  Funding Source German Federal Ministry of Education and Research
  From 1993
  Grant award 168 600 000 EUR

5 most significant results in terms of patents and collaboration with industry:

2017	Consulting, Deutsche Telekom
2014	Big Data for Siemens for 2001, Project Manager
2007	Transfer of TALK research results to Volkswagen Industrial Partner, project leader
2001-2002	Transfer of research results of SmartKom project to industrial partner IDS Scheer AG, scientific leader
1996-1999	Development of the German Natural Language Component for UN (UNL), project leader

5.7. Procured infrastructure and equipment and their necessity and utilisation

As described above in Chapters 4.1 and 4.5, CIIRC currently already has technology and IT equipment that is relevant to this project. However, 3 additional key items need to be purchased for the purposes of the project. Each of these key technologies is specified separately in the tables below. Apart from key equipment, we also plan to purchase additional IT equipment. This equipment is grouped into a functional module entitled "IT module" – these are laptop computers for team members and server.

The list of technology and IT equipment that are planned to be purchased within the project is attached as Annex 26 List of technology and IT equipment. This list shows the item names, number of units, unit prices, links to budget chapters and key activities and other relevant information.
The planned estimated values of individual items of technology and IT equipment were determined on the basis of the price offers received from potential suppliers or on the basis of previously implemented public procurement. The price bids for individual items are enclosed as Annex 29 Price offers.

<table>
<tr><th>Key equipment / functional module
(list descending by price)</th><th>Quantity</th><th>Planned costs
excl. VAT
(CZK thousand)</th></tr>
<tr><td>Industrial robots</td><td></td><td>9 160</td></tr>
<tr><td colspan="3"><u>This module includes the following items:</u>
- Industrial robot with a mobile platform (Kuka LBR 14 R820 + KMR) 1 unit
Price excluding VAT: CZK 4 722 600
- Industrial robot (Kuka LBR 14 R820): 2 units
Total price excluding VAT: CZK 4 437 000

<u>Equipment characteristics:</u>
This is a mobile assembly and a collaborative robot, including connection with stationary collaborative robot. Mobile robot KUKA with a collaborative robot LBR, denoted as KMR (Kuka Mobile Robot), is a fully autonomous mobile robot capable of navigating autonomously indoors, capable of operating safely with respect to persons being in its operating range, and having a sensitive robot Kuka LBR capable of human collaboration. There is no other robot with these parameters available in the market, not even in an experimental setting. KMR has omnidirectional wheels and can position itself with the precision of 1 mm. The robot can communicate with external systems such as Enterprise Resource Planning and perform its function in accordance with the requirements of such systems. It is thus open to further development and integration of custom algorithms e.g. for optimisation or planning.

The stationary collaborative robots will be a natural partner to the mobile robot. They will focus on assembly and other operations in a standalone mode or in collaboration with a human. It is especially the robot's sensitivity due to its force sensors at each joint that provides wide possibilities for solving various research tasks.</td></tr>
</table>

Purpose of the equipment purchased:

The equipment will be used as an additional means of creating flexible production and evaluating procedures for configuring the production flow and production resources depending on the parts being produced. The mobility of the platform provides a variety of options in terms of configuring and modifying the production process, which is one of the key research topics of the project. The collaboration of two collaborative robots and their collaboration with a human are challenges, which are faced by industrial production companies and whose solution is the task for research teams. Within the proposed project this issue will be also addressed as part of the production planning and design of production/assembly cells.

The equipment is related to the System Architecture and System Design work packages, specifically the Semantic Description of Production Resources, Legacy Systems Integration, Service Creation and Implementation and Production Line Design.

Currently, at the Testbed there is no mobile manipulation platform, which is necessary for achieving an appropriate degree of flexibility. KMR can be used as a transport robot but mainly as a manipulator with a sensitive functionality, which can deal with special operations such as robot-robot or human-robot collaboration. The availability of KMR significantly increases production flexibility because production operations can be rescheduled if the currently used resources are fully utilised or if there is an outage of any of them. Mobile and distributed manipulation is an important step towards production planned based on the actual need for a specific type and number of parts produced.

The planned utilisation of the equipment within the project is 100%.

Infrastructure readiness:

These items will be located at the Testbed for Industry 4.0 laboratory in the CIIRC building: Jugoslávských partyzánů 1580/3, Prague 6.

The technology does not require any special readiness except for the availability of a charging station for the KMR battery (3x230V / 50A), which will be provided.

Key equipment / functional module	Quantity	Planned costs excl. VAT (CZK thousand)
Flexible conveyor		**1 308**

Flexible conveyor, 1 unit, Price excluding VAT: CZK 1 307 538

Equipment characteristics:

The conveyor system of type Montrac is a single-track conveyor, along which shuttles move. Each shuttle has its own identification and drive and can move by itself independently of the other shuttles based on the control commands issued by its main controller. There are also track switches that make it possible to change the track for each shuttle. The shuttles can be positioned with a precision of ±1 mm, there is also a positioning and assembly platform available in the system that makes it possible to increase the positioning precision to ±0.1 mm and to act a vertical force up to 2000 N. The conveyor controller can be connected to a superordinate controller using TCP/IP communication. It is also possible to add a lift module that allows for connecting the Testbed with another section focusing on precise machining.

Purpose of the equipment purchased:

The equipment will be used as a means to evaluate concepts of flexible production, which allows reconfiguration and multiple utilisation of workstation. Due to the possibility to plan the path of the conveyor shuttle, to easily exchange the conveyed plate and to utilise the conveyor stops directly as workstations, this technology is required for this project. It will also be possible to use the equipment to test means of centralised and decentralised (agent-based) control.

The equipment refers to the System Architecture and System Design work packages, specifically the Semantic Description of Production Resources, Legacy Systems Integration, Service Creation and Implementation and Production Line Design.

The Testbed for Industry 4.0 already contains the Montrac conveyor but only with three shuttles and a limited possibility to be used as a buffer. Therefore, this proposal includes acquiring additional shuttles, positioning platforms and track switches. Such a configuration makes it possible to create a loop, where free and occupied shuttles can gather, re-order etc. A lift is also added that will connect another part of Testbed in the basement, which will deal with precise machine tooling on machines with high stiffness. This will increase the flexibility of the production line and the shuttles will be used as movable assembly platforms. Any modifications to the capabilities of the shuttles will be performed through robotic operations by the robots, which already are part of the line and which have sufficient lifting capacity to place the necessary part holders and grippers on the conveyor.

The parts required for constructing the conveyor were selected according to an offers that had previously been received from Schmid-Group.

The utilisation of the technology within the project will be 100%.

Infrastructure readiness:

Since this is an extension of the existing conveyor system, the infrastructure will already be ready.

The flexible conveyor will be located at the Testbed for Industry 4.0 laboratory in the CIIRC building: Jugoslávských partyzánů 1580/3, Prague 6, Czech Republic.

Key equipment / functional module	Quantity	Planned costs excl. VAT (CZK thousand)
IT module		**1 120**

The IT module includes the following equipment:

- Laptop computers incl. accessories for members of the research team: 14 units
- Laptop computers incl. accessories for members of the administrative staff: 4 units
- Laptop Macbook Air for members of research team: 3 units
- Laptop Macbook Pro for members of research team: 2 units
- Server: 1 unit

Equipment characteristics:

Laptop computers for members of the research team:

These are laptops that are intended for members of the research team. The performance required for these laptops must be higher compared to laptops for administrative staff. This mainly includes a more powerful processor, more RAM, more SSD capacity etc. In addition to office applications, these laptops must make it possible to run scientific calculations and simulations – e.g. calculations in the Matlab environment. Since researchers often travel with their laptops, a more durable design with a higher proportion of zinc alloys is also required.
As demonstrated in the applicant's other on-going projects, laptops with lower technical parameters do not meet the requirements of research team members and, in turn, are not optimal for use in order to achieve the project's objectives.

The applicant is also planning to buy several 13-inch Macbook Air laptops and two 15-inch Macbook Pro laptops with significant computing performance. These laptops will be lent to DFKI workers during the time of the project, so all the work dedicated to this project will be on them only.

Laptop computers for administrative staff:
These laptops are intended for key members of the project's administrative staff. Within the project, we plan to purchase administrative laptops with lower performance than the ones for researchers. For calculations we used laptops bought from the last CIIRC's public procurement. They are DELL laptops of series 5, e.g. Dell Latitude 5480 with a monitor and accessories. Laptops of a lower series (series 3 – e.g. Dell Latitude 3480) are not adequate for work on the project. Such "entry level" laptops are typically made of mostly plastic parts and, in turn, are not resistant to wear and tear. The work of the project's administrative staff requires frequent travelling and carrying the laptops, which places additional demands on adequate mechanical durability. Therefore, laptops within the mid-range series (series 5) that are designed with a greater proportion of zinc alloys are suitable.

Purpose of the equipment purchased:
The laptops will be used by members of the research team for research and development activities relating to project implementation, and also by key administrative staff. Today, a laptop computer is an essential part of personal equipment for work and will be used for communication, presentations, etc. Specific Macbook Pro laptops will be used by members of the research team for software development.
Currently, the applicant does not have enough laptops to cover the needs of the project team, even with a view to the rapid obsolescence of this equipment.

Server:
The server will be used for developing, piloting and demonstrating the distributed software solutions in accordance with the project plan. Since this work will require putting this equipment outside of the DFKI's firewalls, none of the existing servers can be used for that purpose.

Infrastructure readiness:
Given the nature of the equipment, there are no requirements for infrastructure readiness.
Laptops will be placed directly at the workplaces of individual users, both in the CIIRC Jugoslávských partyzánů 1580/3, Prague 6, and in DFKI. The server will be located in DFKI within the distributed multi-site Testbed laboratory.

Results and outputs of the activity	Target value for project implementation
Indicator: 2 41 01 Number of expanded or modernised research facilities Link to the objectives 4.1, 4.2, 4.3; supported key activity H	1
Indicator: CO25 / 2 05 00 Number of researchers working in modernised research infrastructures Link to the research objectives WP1, WP2, WP3 within the Chap. 5 Feasibility study	36.887
Indicator: 2 05 02 Number of researchers working in upgraded research infrastructures - women Link to research objectives WP1, WP2, WP3 within Chap. 5 Feasibility study	4.250
Another result that is not reflected in the indicators: Output: Devices acquired and material equipment: Module I: Industrial Robots Module II: Flexible conveyor Module III: IT module Link to objectives 4.1, 4.2, 4.3 and to research objectives WP1, WP2, WP3 within Chap. 5 Feasibility study; supported key activity H	 1 1 1

6. MEMBERSHIP IN PROFESSIONAL ORGANIZATIONS / PLATFORMS / CONSORTIA

The research team of the consortium is now involved either through specific individuals or as an organization involved in leading professional organizations and platforms relevant to industrial production. The goal is still to focus more on the industry-specific international platforms of Industry 4.0 or those close to the principles of Industry 4.0.

CIIRC CTU is then specifically a member of the following entities:

- **The Industrial Data Space Association (IDSA)** – ever since its foundation in 2016, IDSA has been growing, among other things, thanks to the attractive original idea of a secure and partially self-contained sovereign data exchange that can take place outside of companies and countries. Since 2017, CIIRC CTU has been one of 78 members who want to contribute to the development of working with data in a safe environment. Data Exchange and Interoperability are major demands of Industry 4.0. It is very important to understand data sovereignty as a key part of today's solutions in industrial IT and automation on a global scale and to offer ways how to unify it. In

IDSA, data are stored including their semantic description, providing a good basis for their integration into other systems. This is fully in line with the main vision of the “Cluster 4.0” project, in which semantic data are intended to be generally described and then interconnected with the services offered by different production companies. The project will contribute to the IDS with the semantic description of services and production resources as an extension to the current described data. Thanks to IDSA membership, we will be able to contribute with the project results in IDS.

- **SAP University Alliances (SAP UA)** – SAP offers access to university departments to its IoT SAP HANA platform, including the ability to use APIs and libraries for data analysis and work with large amounts of data stored in the SAP HANA database. CIIRC CTU has been a member of SAP UA since 2017 and uses the tools for educational purposes in the subject “Industrial Information Systems” in the programme “Cybernetics and Robotics”. This participation has both educational and application benefits. The educational benefits are both for teachers (WP leader Petr Kadera) and for students who can get involved faster in projects related to large data processing and IoT. We expect this knowledge to be beneficial in getting new researchers to the Cluster 4.0 project. Application benefits will be reflected in the implementation of project results into industrial tools - through SAP HANA, the implemented methods will be closer to real use in an industrial environment. Last but not least, there is a social benefit in terms of establishing new links and contacts with other research teams operating in SAP UA. We will continue to maintain the membership in SAP UA.

- **PROFIBUS & PROFINET International (PI)** – PI, the international organization, is the proponent of PROFIBUS and PROFINET, the most widely used automation technologies in the world. The participation of the team members (e.g. the project manager of the Cluster 4.0 project, Pavel Burget) in technical working groups, which are mainly occupied by representatives of major industrial companies with global impact (Siemens, Bosch Rexroth, Phoenix Contact, ABB, Hilscher, Molex etc.) enables direct involvement in the development of new standards. In connection with Industry 4.0, there are several standards to be developed, e.g. the integration of OPC UA into Profinet's application profiles, the classification of products and services by the eCl @ ss consortium and/or the mapping of communications services to the new IEEE 802.3 layer transfer according to TSN (time-sensitive networks), etc.

- **PLCopen** and **AutomationML** – both are organizations dealing with unifying rules and developing standards for industrial automation, especially for industrial control systems. One of the latest PLCopen initiatives involves recommendations for the implementation of the administration shell (AS) of the product from the point of view of industrial PLCs. AS is a concept defined in Industry 4.0 for industrial component interfaces that comprehends their virtual representative including their technical functionality. The working document for the AS was created within the Industrie 4.0 platform, a consortium that leads the direction of Industry 4.0 in Germany. AutomationML is a standard that uses PLCopen to describe the code and structure of control systems and combines it with other descriptions such as CAD data and kinematic machine descriptions. This standard is also being applied in industrial projects (e.g. Daimler is one of the major operators). We will continue to monitor its development so that we can continuously assess its suitability for the results of the Cluster 4.0 project.

- **euRobotics AISBL (Association Internationale Sans But Lucratif)** - an international non-profit association based in Brussels, representing all European robotics stakeholders, in particular institutions and academics and industry experts. CIIRC CTU is represented in euRobotics CTU since March 2014 as its 148th member. One of the association's main missions is to collaborate with the European Commission (EC) to develop and implement a strategy and a roadmap for research, technological development and innovation in robotics. euRobotics builds upon the success of the European Robotics Technology Platform (EUROP) and the academic network of EURON, and will not only continue the cooperation but will also strengthen the bond between members of these two community driven organisations. Thus, leading towards the establishment of only one sustainable organisation for the European robotics community as a whole. euRobotics Aisbl has over 250 Member Organisations representing all sectors involved in Robotics, i.e. research organisations, universities, manufacturers, system integrators, end users, etc.

Existing memberships in other associations:

- **Machine Tools Association** (impact area: the Czech Republic). The Association brings together businesses and individuals operating in the development and use of machine tools. Membership in the Association makes it possible to acquire latest industry-related information and share it with all members, attend educational events and professional workshops in the field of machine tools. The Association's activities allow for establishing efficient links between companies and research institutes in the area of educational, research and development cooperation.
- **Czech-Moravian Society for Automation** (impact area: the Czech Republic). The Society brings together businesses and individuals operating in the field of industrial process automation. Membership in the Society makes it possible to share latest information with all members and attend educational events and professional workshops in the field of automation. The Society's activities allow for establishing efficient links between companies and research institutes in the area of educational cooperation.
- **Association of Engineering Technology** (impact area: the Czech Republic). The Association was established mainly to promote and protect its members' common interests and to coordinate their collaboration in all areas where a common approach is useful in implementing business plans. Currently, the Association brings together most companies and organisations operating in this field in the Czech Republic. In the Czech Republic, companies that are associated within the Association account for more than 70% of the production of machine tools. Other products of the businesses in the Association are also significant, e.g. woodworking machines, casting machines for casting under pressure, hydraulic equipment, ball screws and nuts, motors, tools and gauges/meters. Membership in the Association allows companies and organisations to access industry-related statistical information, support the promotion of the interests of the Association's member enterprises in dialogue with public administration and social organisations in the Czech Republic, and to actively cooperate with CECIMO (see below).
- **Technology Platform of Engineering Production Technology** (area of impact: the Czech Republic). The Platform consists of manufacturing companies, research organisations and association that

have been operating for a long time in the “Machine tools” field in the Czech Republic. The Platform’s main objective is to contribute to the development and competitiveness of the machine tool sector through supporting applied research in the field. The Platform is the only and ultimate grouping in the field, which formulates a long-term research strategy that provides a basis for subsequent implementation into specific R&D projects.

- **Czech Technology Platform ENGINEERING** (impact area: the Czech Republic). The platform brings together and supports the activities and initiatives of organisations working towards the development of the engineering industry in the Czech Republic and the related scientific, research, technology and innovation activities.
- **European Technology Platform Manufuture** (impact area: EU). The mission of the Platform is to propose, develop and implement a strategy based on Research and Innovation, capable of speeding up the rate of industrial transformation to high-added-value products, processes and services, securing high-skills employment and winning a major share of world Manufacturing output in the future knowledge-driven economy.
- **CECIMO** (impact area: EU). CECIMO is the European Association representing the common interests of the Machine Tool Industries globally and at EU level. It brings together 15 National Associations of machine tool builders, which represent approximately 1300 industrial enterprises in Europe (EU + EFTA + Turkey), over 80% of which are SMEs. CECIMO covers 98% of total Machine Tool production in Europe and about 36% worldwide. It accounts for almost 150,000 employees and a turnover of more than €24 billion in 2016. Approximately 75% of CECIMO production is shipped abroad, whereas around half of it is exported outside Europe. CECIMO assumes a key role in determining the strategic direction of the European machine tool industry and promotes the development of the sector in the fields of economy, technology and science. Membership in the Association allows companies and organizations access to sector-specific statistical information and promoting the members’ interests in dialogue with the European Commission and other EU bodies.
- **EFFRA - The European Factories of the Future Research Association** (impact area: EU). The Association is a non-for-profit, industry-driven association promoting the development of new and innovative production technologies. It is the official representative of the private side in the 'Factories of the Future' public-private partnership. The key objective of EFFRA is to promote pre-competitive research on production technologies within the European Research Area by engaging in a public-private partnership with the European Union called 'Factories of the Future'. EFFRA was established jointly by the MANUFUTURE technology platform and key industrial associations to shape, promote and support the implementation of the ‘Factories of the Future’ public-private partnership. The partnership aims to bring together private and public resources to create an industry-led programme in research and innovation with the aim of launching hundreds of market-oriented cross-border projects throughout the European Union. Such projects will produce demonstrators and models to be applied in a wide range of manufacturing sectors.
- **CIRP - The international academy of production engineering** (impact area: world). CIRP is the world leading organization in production engineering research and is at the forefront of design, optimization, control and management of processes, machines and systems. The Academy has restricted membership based on demonstrated excellence in research and has some 600 academic and industrial members from 50 industrialized countries. The vision of CIRP is to promote research and development among its members from Academia and Industry to

contribute to the global economic growth and well-being of society. The mission of CIRP is to develop the highest-level international network of eminent Researchers and Industrialists for the purpose of marshalling their knowledge and insights. Individual membership in CIIRP is an acknowledgement of a person's highest standing in the field of manufacturing engineering. Corporate membership in the Academy ensures the transfer of the latest important findings from research into practice

CIIRC CTU has been involved in Industrial Data Space Association (IDSA) since 2017 - see Chapter 4.2. For the purposes of this project, further support for the implementation of the Industry 4.0 concept is to strengthen and further develop activities in those platforms rather than creating new clusters. At the same time, thanks to the experience of the DFKI partner and his involvement in standardization workgroups in existing different initiatives in Germany (e.g. Plattform Industrie 4.0), CIIRC CTU will be able to implement such procedures in the Czech Republic. From this point of view, it is crucial to focus on IDSA membership, further develop activities at SAP University Alliances, PI, PLCopen, CIRP, etc., and to join the newly created ADAMOS platform. ADAMOS aims to create a platform for manufacturers and users of machines, which will act as a digital market and will offer services to ADAMOS customers. Moreover, ADAMOS will serve as a platform for IoT, but above all, it will create standards that will allow to manufacturers easier integration and offers to customers of their machines based on the motto "Machine manufacturers for machines manufacturers". Participating on this platform in connection with the multi-denomination approach in defining the services and product features by semantic description will support the machine domain. This minimizes the risk that project results in this domain will not meet the requirements of the market. Participation in the ADAMOS platform is an appropriate addition to membership in organizations such as the Machine Tooling Company, Engineering Machinery Association, or the Technological Platform of Engineering Production Technology, which multiplies the impact of the results of the Cluster 4.0 project.

Based on this experience, a new superstructured interface will be created within this project, which will allow the existing platforms to be linked without having to create new structures. Synergistically, a network of cooperating entities will be used under NCI4.0 and other partnerships.

Results and outputs of the activity	**Target value for project implementation**
Another result that is not reflected in indicators: Planned memberships in professional organizations / platforms / consortia Output: membership, resp. deepening activities resulting from membership in IoT platforms Link to the supported key activity K	3

7. PROJECT MANAGEMENT

Project will be implemented by the administrative and the scientific team.

The participating research group will be responsible for:

- Fulfillment of scientific project activities;
- Creating project outputs and outputs;
- Active work with the target group and partners
- Achievement of the planned objectives of the project, including the fulfillment of the planned indicator values.

The composition of the research group and the role of the individual members is described in Chap. 5.

The administrative team is responsible for:

- Formal coordination of the project;
- organizational and operational aspects of the project;
- Ensuring effective communication at all levels of project implementation (towards the funding authority, the management of the main beneficiary, project partners and project staff).
- Financial management of the project;
- Continuous project monitoring;
- Preparation and settlement of monitoring reports and payment requests;
- All other administrative acts defined by OP RDE rules and conditions given the administration of projects from ESIF or requested by the Funding Authority or other public administration bodies.
- Co-operation in project audits and project monitoring;
- Obligatory publicity of the project;
- Documentation and archiving of documents according to OP RDE rules and legal norms;
- Supervision over the project's timing with regard to the proposed timetable;
- Coordination, methodical management and supervision of the selection processes, especially with regard to valid legislation and OP RDE rules;
- Supervision over compliance with public aid rules (basic obligations linked to public aid rules are set up in internal regulations);

The size of the administrative team was determined with respect to the practice of the evaluators in the OP RDE Support for Excellent Research Teams Call, where the evaluators set as an adequate level of 2-3 FTE of administrative team for projects with a volume of about CZK 130 million. For this submitted Cluster 4.0 project of about CZK 100 million, we respect this evaluators practice and assume a level of 1,6 FTE for an administrative team.

The composition of the administrative team and the role of individual members is given in following table:

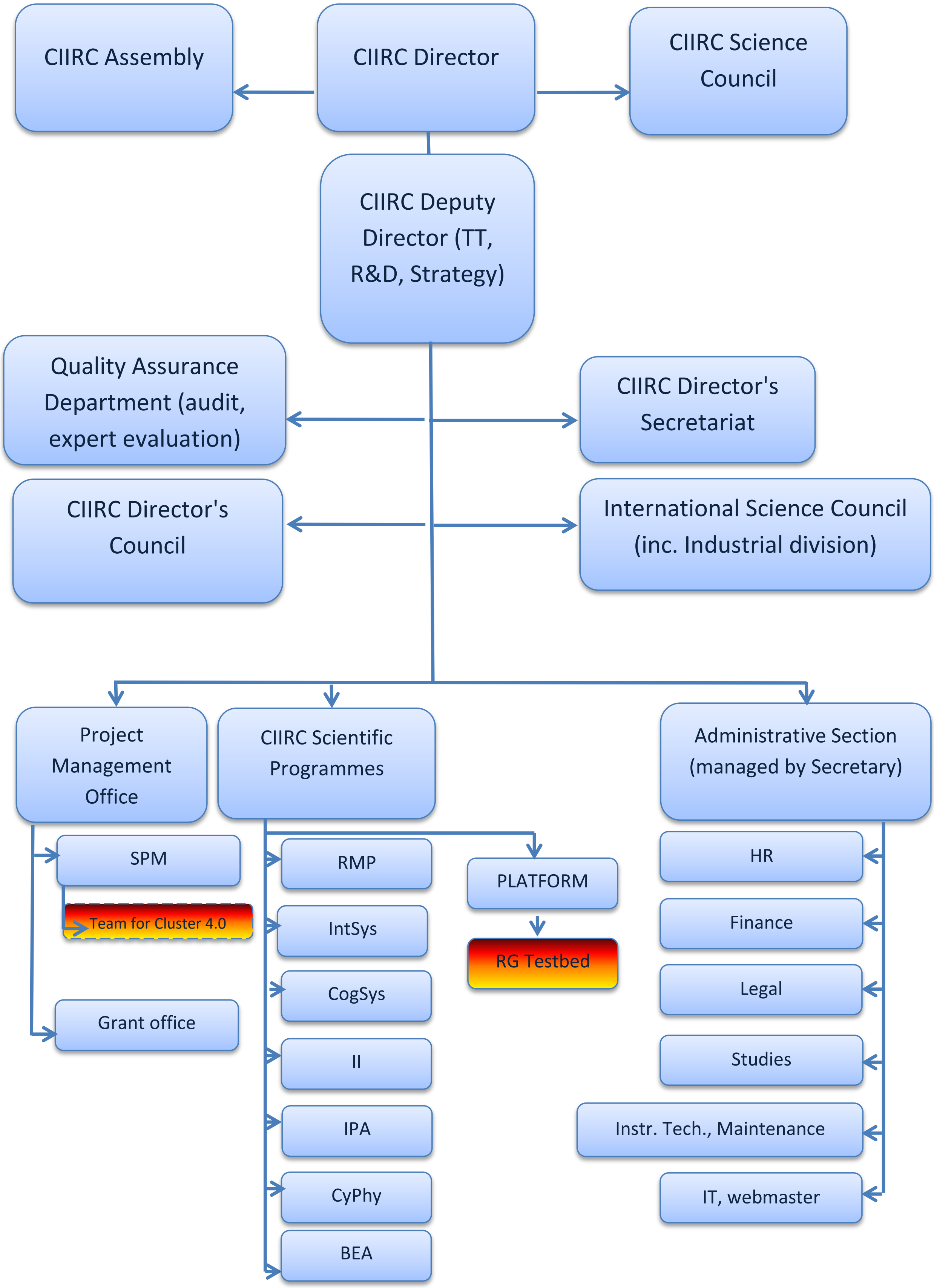
First and last name (for open positions please indicate "to be nominated")	Staff member type - key - ordinary member	Position in the team (project manager, accountant, ...)	FTE during the project implementation period The years indicated are calendar years and correspond to project budget years.					
			2017	2018	2019	2020	2021	2022
to be nominated	ordinary member	project manager	0	0,3	0,3	0,3	0,3	0,3
to be nominated	ordinary member	financial manager	0	0,4	0,4	0,4	0,4	0,4
to be nominated	ordinary member	project specialist	0	0,5	0,5	0,5	0,5	0,5
to be nominated	ordinary member	project assistant	0	0,4	0,4	0,4	0,4	0,4

Qualification prerequisites for open positions. Indicate for positions you plan to fill with key and leading staff members.	
Staff member position	**Qualification prerequisites**
project manager	• University degree or relevant work experience • documented experience in project management and complex administrative project management • advanced PC skills and MS Office skills • excellent proficiency in English
financial manager	• University degree or relevant work experience • demonstrated experience in financial management • advanced PC skills and MS Office skills • excellent proficiency in English

7.1. Planned organisational structure during the project implementation term

The project administration (a contact for the OP RDE Managing Authority) will be carried out within the CIIRC Project Office, which will provide the relevant cooperation within Administrative section, in particular the Accounting Department and the Personnel Department. Based on the complex nature of ESIF project administration, the Project Office is a separate section directly subordinated to the CIIRC Director. Within the project office, the project will be integrated into the team of Strategic Projects Management (SPM), which is responsible for the administration of long-term and cross-sectional projects, especially OP RDE projects. Implementation of the scientific part of the project (for more details, see Chapter 5) will take place within the research group Testbed integrated in the Department of Research Management and Platforms, which is used to horizontally integrate scientific teams at CIIRC CTU.

CIIRC Organisation Chart



7.2. Risk analysis

The main risks that may possibly arise from the planned research and during the project implementation are described below. The probability, impact and foremost the risk-prevention and risk-mitigation measures are associated with the objectives and specific activities of the project. The analysis comprehends risks related to the project operation and financial and administrative management. Risks related to research and educational tasks are also included.

General mitigation strategy and risk management

Regarding the fact that the project implementation is very demanding and the risk management becomes the indivisible part of the implementation strategy. The risks can be identified as follows: technical risks, financial risks, and internal and external risks. The technical risks are associated with the specific technological aspects of the project and the eventual issues with achievement of a certain required level of the developed technologies, the samples and technology malfunctions, their technological obsolescence during the project implementation etc. The financial risks concern the effective management and finances control within the participating organizations. The internal risks are related to the project management and include inability to fulfil the partial aims of the project, the staff department changes or the schedule alteration. The legislative risks, risk of inflation, interest rate movement risks or risks qualified as Vis Major are considered to be the most significant external risks. In the analysis bellow, the technical risks are considered as scientific risks and the financial, internal and external risks are considered as administrative risks.
The risk assessment will be continuously conducted during the whole project realization to be sure the consortium will be able to fulfil the project goals on time and on budget. The risk management process consists of following steps:

- Risk identification and characterization
- Risk evaluation (qualitative and quantitative)
- Risk prioritization
- Risk response planning – mitigation strategies
- Risk controlling, monitoring and reporting

Regular update of the risk analysis and contingency plan will be realized on bi-annually basis under the authority of the PIs with the both co-PIs, who are responsible for keeping the analysis up to date and are responsible for the risk management process. Obviously, there are two types of risks – administrative and organizational risks on the one hand and the scientific risks on the other hand. In case several risks occur at the same time, the risk with the highest impact will have the priority to be mitigated.

RISK ANALYSIS					
No.	**Description of potential risks**	**Probability**	**Impact**	**Related objectives**	**Proposed risk-prevention and risk-mitigation measures**
Project implementation risks (related to financial and operational project management)					
1	Low willingness to participate in the intersectoral network	LOW	MEDIUM	1	The concept of the "Network of Trust" creates superstructure system connecting existing data platforms, thus simplifying the communication and data sharing between industrial partners. Joining the network is an opportunity, as the idea is beneficial for industry.
2	Insufficient commitment to the project goals, esp. to the methodology concept	LOW	HIGH	2	The willingness of the project implementation was approved by the project partners based on the Letter of Intent (Expression of Support).
3	Disinclination of researchers to implement the peer-review system	LOW	LOW	2	The career rules will be established based on a well-grounded system of key performance indicators (qualitative and quantitative KPIs) in order to motivate researchers in career development.
5	Ineffective project coordination	LOW	MEDIUM	1	The project will be coordinated according to standard processes and procedures. The rights and obligations of the project coordinator will be established in the Cooperation Agreement between project partners.
6	Insufficient communication	MEDIUM	LOW	3	The communication strategy and effective flow of information will be set up at the beginning of the project with the aim to enable systematic and prompt sharing of information between the project team, public and existing and potential partners.
7	Low experience with the BD&TT strategy and IPR implementation	LOW	MEDIUM	2	The strategic document of CIIRC CVUT will be based on wide experiences of industrial partners with the commercialisation. The basic principle is the sharing of IPRs based on the participation on the IPR development.
8	Difficult interaction with industrial representatives and stakeholders influencing the BD&TT advancement	MEDIUM	HIGH	2	CIIRC is in close cooperation with the industrial sector based on the collaborative and contractual research and offers the partnership in the NCP 4.0. The variety of transparent communication channels will be at place to prevent such risk.
9	Low financial budget to support research mobility	LOW	LOW	4	This risk is prevented by the sufficient financial amount dedicated to short-term research stays in the project budget. The partnerships (with industry and academia) and related projects (running/planned) would possibly

					allow to cover some of the costs exceeding the budget dedicated to research mobility.
10	Delay in recruitment of new researchers	LOW	MEDIUM	all	Reliable and transparent recruitment services / processes. Motivation policy in terms of career development and system of remuneration.
11	Reduce in EU structural funding and further possible obstacles	MEDIUM	MEDIUM	6	In case the structural funds are reduces, the institution will mainly focus on the international (H2020) schemes and fundraising strategy. The other possible obstacles include changes in the rules of participants of the call and other risks that could cause delays and further additional work. Those risks will be mitigated by prompt and open communication with the Ministry.
12	Delays in public procurement - purchase of equipment	MEDIUM	MEDIUM	5	The mitigation actions comprehend: qualified public procurement support, esp. staff knowledgeable in public procurement legislation; implementing a personal liability system; transparent and proactive procurement policy rules.
13	Lack of competitive national/international funding schemes for industrial cooperation	LOW	MEDIUM	6	The H2020 strategy for years 2018-2020 include variety of calls related to Industry 4.0 topics. Even SME instruments or e.g. participation of EIT Digital call would enable reaching further financial sources in cooperation with industry.
Risks related to research and educational tasks					
14	The actual needs of industry will be not covered by the technology possibilities of the Testbed for Industry 4.0	MEDIUM	HIGH	1	The risk will be mitigated by the state-of-the-art equipment placed in the Testbed facility. Moreover, the planned connection to testbeds in Brno and Saarbruecken are planned to even enhance the current technology possibilities.
15	Lack of students and low interest to study in the new PhD programme	MEDIUM	MEDIUM	4	The new PhD programme will be focused on attractive area of Industry 4.0 and will include specialisations solving current needs of industry (e.g. industrial automation, informatics, robotics, manufacturing and transport systems, and others)
16	Development of a new disruptive technology that will completely change the area	LOW	HIGH	5	The project targets on highly up-today and current demands on the production: targeting on planning, construction and commissioning, ramp-up and series production. There is a low probability that a new disruptive technology would change the current situation at the industry and market in a short term horizon.
17	Low demand for services and development	MEDIUM	MEDIUM	5	The risk will be mitigated by appropriate number of industrial partners entering the new network and using the newly established platform. In case such problem occurs, the new strategy for targeting industrial partners will be set up as well as the further propagation of the Testbed facility.

18	Existence of similar platform developed at other technical institutions, thus increasing the competitiveness	MEDIUM	LOW	all	There are already several platforms and clouds dealing with the data storage. An important aspect of the project is a strong linkage to existing industrial software or open-source solutions which allows incorporating the project results into existing systems. In case that other platform arises, it can be successfully integrated into the network.
19	Loss of key persons from scientific team with no adequate replacement.	LOW	MEDIUM	all	Prevention is a consistent way of replacing the key persons with existing staff. The substitution of the key persons is the priority.
20	Missing or insufficient data for some target applications	LOW	HIGH	1	The team includes experts with experience in collecting and annotating of experimental data. The work plan first deals with the publicly available data before targeting on the application-specific data. The network of industrial companies is the key source of relevant data needed to create the superstructure application/software.
21	Low success in highly-competitive H2020 calls	MEDIUM	MEDIUM	6	This risk will be mitigated by the appropriate funds/grants strategy. Moreover, the Grant Lab will enable cooperation with international and more experienced grant managers, thus enabling transfer of knowledge and best praxis.

8. Securing co-financing in the implementation stage

Co-financing will be provided both by CIIRC CTU and by the partner institution DFKI.

CIIRC CTU plans to provide project co-financing in an amount of 5% of total eligible expenditure from its own resources obtained from its economic activities. The project's total eligible expenditure is CZK 98.7 million, i.e. total co-financing is CZK 4.9 million.

Total eligible expenditure for CTU is CZK 71.8 million, co-financing by CTU for the entire duration of the project is: CZK 3.6 million. Expected co-financing in each year of the project is shown in Table.

Expected co-financing in years of project – CIIRC CTU

CZK thousand	2018	2019	2020	2021	2022	**TOTAL**
Planned co-financing	1037	665	694	680	515	**3 591**

The following Table shows the current situation of revenue from economic contracts in 2014–2017. The amount for 2017 is for the period from January to August, so the total amount for 2017 will be higher.

Annual revenue from business contracts at CIIRC:

Data as at 1 September 2017	2014	2015	2016	2017	**TOTAL**
Successful economic contracts	6 688	5 341,5	9 320	9 783,5	**31 133**

The average co-financing amount (CZK 718 ths. per year) is available - although only from a reasonable profit under the Community Framework for RDI Support (about 10-20%), so this resource has sufficient capacity to co-finance the project. The institutional support (max. 5-8% from all the support) will compensate the potential decrease in revenues from contractual research.

DFKI will provide co-financing for its part of the budget (total DFKI: CZK 26.8 million, co-financing: CZK 1.34 million).

DFKI dispose of a huge financial budget that can cover the participation in the project. Since the usual participation of DFKI in projects counts to 20-40%, the 5% co-ownership of the project is a marginal cost burden in relation to the total subsidy.

DFKI's financial resources are derived from providing consultancy services and collaborating on research and development with industrial partners, especially DFKI shareholders (e.g. SAP, Microsoft DE, RICOH, CLAAS, BOSCH, Deutsche Telcom, BMW Group, Volkswagen, full list of shareholders available at https://www.dfki.de/web/about/shareholders). However, DFKI is a non-profit organization, therefore reinvests all the profits from these projects into the main R&D activities, including the co-financing of individual projects.

9. SUSTAINABILITY

The factual and financial sustainability of the project will be ensured. The main feature of the project sustainability is to maintain the research team and to enable its further development. A detailed description of financial sustainability is given in the table in Chap. 9.1, substantive sustainability is described in Chap. 9.2.

9.1. Financial sustainability

Plan for financial sustainability of the project (CZK)					
Item, inc. comments	1. year	2. year	3. year	4. year	5. year
Personnel costs We assume a gradual increase in involvement of the team members each year, compared to the last year of implementation by a total of 10%, aiming to increase the level, quantity and quality of the research team.	3 391 224	13 564 896	13 971 843	14 026 102	14 053 232
Travel costs We expect growth in the same proportion as the increase in the project team members.	659 271	2 637 084	2 716 197	2 726 745	2 732 019
Services We assume a stable amount as in the last year of implementation.	456 555	1 826 221	1 826 221	1 826 221	1 826 221
Administrative costs (local office) Together with the growth of the realisation team, a similar increase in administrative and associated costs can be expected.	463 658	1 854 631	1 910 270	1 917 688	1 921 397
Maintenance/repairs We expect marginal costs to enable the use of equipment acquired in the project even in the sustainability period.	0	50 000	50 000	50 000	50 000
Consumables/material Due to the development of the whole team, a similar increase in the need for material equipment can be expected.	50 567	202 267	208 335	209 144	209 548
Technology We do not expect investment costs There will be in kind contributions from cooperating manufacturing companies	0	0	0	0	0
Total operational costs	***5 021 275***	***20 135 099***	***20 682 865***	***20 755 900***	***20 792 418***
Operational revenues in accordance with Article 61 for non-revenue-generating projects (revenues are not sufficient to cover full operational costs and are subject to further restrictions)	*0*	*0*	*0*	*0*	*0*

Demands for own financial contribution (Total Operating Expenses - Operating Incomes), a nonzero positive value is generated	***5 021 275***	***20 135 099***	***20 682 865***	***20 755 900***	***20 792 418***
Financial resources: institutional support We expect institutional support of 10% of expenditure in the sustainability period. This institutional support will mainly be used to secure administrative expenses.	*502 127*	*2 013 510*	*2 068 286*	*2 075 590*	*2 079 242*
Financial resources: grants/fundraising The emphasis will be put on grant opportunities and the grant resources, which will be achieved by the project team based on previous experiences and due to successful fulfilment of project indicators (2 international H2020 grants received during the implementation phase). We expect the average project budget in the H2020 grant about CZK 4.5 million, the average duration of the grant is 3 years. Thanks to strategic cooperation with the prestigious DFKI centre and industrial partners, success in the highly competitive H2020 (ECSEL, ICT, EIT, SME Instruments etc.) funding schemes can be expected. We assume that the grants obtained in the implementation phase will mainly cover the first half of the sustainability period. Planned international grants in the sustainability period will be the main source of funding in the second half. In total, there are five grants planned to be received. In addition to international grants, we also consider financial income from two national grants, here we expect an average annual amount of CZK 2, 5 million per each.	*1 525 000*	*14 100 000*	*14 450 000*	*14 675 000*	*14 750 000*
Financial resources: contractual research We expect a growing attractiveness of the research team for industrial partners. We consider revenues from contractual research at 20% of the planned budget in the sustainability period.	*4 017 020*	*4 027 020*	*4 136 573*	*4 151 180*	*4 158 484*

Financial resources: others Other relevant sources of funding (we account for 1% of the planned budget) include, for example, donations that can be expected due to the growing cooperation with individual industrial partners.	*0*	*201 351*	*206 829*	*207 559*	*207 924*
Financial resources - total	***6 044 147***	***20 341 881***	***20 861 688***	***21 109 329***	***21 195 650***
Remaining costs Revenues in the sustainability period are estimated to be sufficient to cover planned project needs. The financial sustainability of the project is therefore secured.	*0*	*0*	*0*	*0*	*0*

9.2. Substantive sustainability

In the sustainability period, we plan to maintain and moderately expand the team in terms of FTE, and we expect to improve its quality. Junior researchers expected to be involved in the project will gradually replace the senior ones, so that we will have a higher proportion of workloads between key and excellent staff. New juniors will be recruited to their positions to ensure continuous development.

Based on new experience gained during the project implementation, we also expect to gain the necessary knowledge and best practice from a strategic partner, which is essential for successful bidding in highly competitive foreign calls. The project assumes two international projects and five newly established cooperation with enterprises as main binding indicators. Three international grants are planned for sustainability. These grants will then enable the team development. Thanks to the strategic cooperation with the prestigious DFKI centre and the direct link to global industrial players (AIRBUS, ŠKODA), success in the highly competitive H2020 (ECSEL, ICT, EIT, SME Instruments etc.) funding schemes can be expected. The first three years of the research team's sustainability will thus be covered by most of these received grant resources. The second half of the sustainability period will include additional funds obtained from H2020, resp. similar grant programs. We expect further financial resources from other successful national grants.

Cooperation with the industrial sector will also be extended. Thanks to the unique capability of long-term verification and improvement of project outputs, new impetus will be gained, bringing new research topics, and industrial cooperation will be the source of research activities for new projects. Collaboration with industry partners will also make it possible to verify the functionality of links with the industrial sector and their consolidation. This will allow the emergence of links with new actors and the promotion of best practice even in this respect.

With team development and new research topics and thanks to immediate feedback from practice, we also anticipate an increase in publishing activity and the emergence of new patents.Publishing activities keep the stable trajectory with slight continuous increase.

The remaining part of the resources needed for the full sustainability of the research team and its organic development will not be covered by subsidy resources, but it will be secured by contractual research from successfully concluded industrial contracts (at least 2) in the last year of the project implementation. Considering the attractiveness of the proposed topic and the expected interest of the companies in the project output (especially the SW superstructure over the IoT Platforms), the increased and prominent interest of the industrial sphere in economic cooperation with CIIRC CTU will be visible in the sustainable period. On the other hand, patent revenues (despite the expected patents) are not considered in the sustainability plan, as effective commercial use of patent rights (e.g. through licenses or direct sales) usually requires a longer time horizon. The rate of contractual research in the total resources needed to ensure the sustainability of the project will be subject to the maximum threshold (20%) resulting from the Community Framework for RDI Support (2014 / C 198/01). For quantitative expression, see the table in Chap. 9.1. From the point of view of the investment plan, the development of technological and SW equipment is foreseen in the sustainability period in the form of in-kind contributions from cooperating manufacturing companies (e.g. SIDAT, SIEMENS). We do not consider any spending on investments.

The administrative capacity needed to support the team will be covered by the CIIRC's institutional resources, with an estimated 10% of expected expenditure.

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Code and title of the result	Target value for project implementation	Plan of developments in the sustainability period				
		Year 1	Year 2	Year 3	Year 4	Year 5
2 03 12 Number of participations of supported research teams implemented within international cooperation programmes	2		1		1	1
CO26 / 20000 Number of enterprises cooperating with research institutions	2	2	3	5	5	6
2 02 11 Professional publications (selected types of documents) created by supported entities	18	4	4	5	5	6
20213 Professional publications (selected types of documents) co-authored by research organisations and enterprises	4	1	1	1	1	2
2 02 16 Professional publications (selected types of documents) with foreign co-authors created by supported entities	8	2	2	2	2	3
2 20 11 International patent applications (PCT) created by supported entities	1			1		1
Another result: Software for non-commercial use	1					1