ENVIHEI

# Title of the PBL challenge: **Robotics in Transportation Systems**

**Name of the responsible lecturer**

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**University / Department / Degree program**

Silesian University of Technology / Department of Engineering Processes Automation and Integrated Manufacturing Systems / Bachelor's Degree in Industrial Automation and Robotics

**Course / Subject in which implemented**

3rd Course / Robotics in Transport Systems

**Implementation period (dates)**

March 1, 2026 – June 19, 2026

**Total duration (weeks/hours)**

8 weeks / 15 hours

**Number of students involved**

55 students

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# 1. Project Design

## 1.1 Brief description of the project and the challenge proposed

The project was conducted as part of the regular project-based coursework associated with the Robotics in Transport Systems subject. A total of 55 students participated in the activity, organized into three course groups: two full-time groups and one part-time group, which were further divided into 12 project teams (five for part-time students, and seven for full-time students). The primary objective of this project was to develop students' ability to independently solve engineering problems, collaborate effectively in teams, assume specific project roles, and understand the importance of sustainability in modern industrial engineering. Although the overall project objective was similar for all participants, the detailed requirements differed between full-time and part-time students due to differences in the number of contact hours allocated in their study programs. Full-time students received less predefined input data and were given greater freedom in shaping the project's scope, assumptions, and technical solutions. In all cases, the general objective was the robotization of workpiece transport between an input storage area, a CNC machine tool, and a finished-parts storage area. Students were required to replace manual material handling operations with an automated robotic solution while ensuring the technical feasibility and efficiency of the proposed system.

For the full-time groups, the project specification included a description of the workstation, an outline of the machining process, and a predefined workpiece in the form of a machine shaft with specified dimensions. Students were tasked with developing a concept of a robotized machining cell capable of performing the material handling operations previously carried out by a human operator. In addition to technical and economic considerations, the proposed solutions were required to address environmental protection issues, sustainability principles,

and selected Sustainable Development Goals (SDGs). The developed concepts involved the selection of suitable industrial robots, grippers, machine tools, transport equipment, the design of workstation layouts, and the definition of robot trajectories.

The part-time students were assigned a modified version of the project with a stronger emphasis on energy efficiency assessment. Their task focused on evaluating the energy performance of alternative robotic transport solutions and identifying opportunities for reducing energy consumption while maintaining the required production performance. The machining applications addressed within the projects included components such as machine shafts, brake discs, pins, and plate-shaped parts. Students compared alternative system configurations in terms of cycle time, productivity, energy efficiency, and environmental impact, demonstrating how robotic automation can contribute to more sustainable and efficient manufacturing systems.

## 1.2 Expected learning outcomes (academic and transversal competences)

The project was designed to develop both discipline-specific knowledge and sustainability-orientated transversal competencies. From an academic perspective, students were expected to evaluate the solution using a multi-criteria approach that combines technical and environmental performance indicators. Technical assessment focused mainly on manufacturing-related metrics such as cycle time or productivity, and safety, whereas environmental evaluation considered factors like energy consumption, robot trajectory length, and the number of non-productive movements within the automated system. In the case of full-time studies, the assessment of energy consumption, trajectory length, and idle movements could be carried out using any method, including estimation. This approach encouraged students to move beyond traditional

efficiency-orientated analyses and to consider the broader implications of engineering decisions.

The key academic competences acquired included:

- Selection of industrial robots for manufacturing applications.
- Design and conceptualization of machine safety systems.
- Production flow and material handling analysis.
- Integration of Autonomous Mobile Robots (AMRs) into manufacturing environments.
- Analysis of automation and robotization opportunities in industrial processes.

In the case of transversal competences, the following have been achieved:

- Teamwork and collaborative problem solving.
- Independent decision-making.
- Project management and task planning.
- Communication and presentation skills.
- Role assignment and responsibility management.
- Conflict resolution during the design process.
- Creativity and brainstorming.

In parallel, the project supported the development of key sustainability competences. Systems thinking was promoted through the analysis of relationships between technological design choices and their environmental consequences. Critical thinking was fostered by requiring students to assess alternative solutions not only in terms of technical performance but also with regard to sustainability criteria. Integrated problem solving was promoted by challenging students to combine engineering knowledge with environmental considerations in order to propose balanced and responsible solutions.

## 1.3 Targeted sustainability competences

Educational activities were also linked to the United Nations Sustainable Development Goals (SDG). Through this alignment, students were encouraged to situate engineering design decisions within a broader, multi-dimensional framework of sustainability considerations and recognize the role of automation and robotization in supporting more resource-efficient manufacturing systems.

By working on the project, the students become familiar with the following aspects:

- Lifecycle thinking and sustainable engineering design.
- Resource efficiency.
- Assessment of environmental impact.
- Sustainable decision making.
- Energy efficient manufacturing.
- Responsible use of automation and robotics.

Overall, the project integrated technical thoroughness with sustainability awareness, enabling students to develop competences required for the design and evaluation of modern manufacturing systems while developing awareness of the environmental and societal responsibilities associated with engineering.

## 1.4 Sustainability approach and how it is integrated into the project

Sustainability was integrated into the project at the stage of problem formulation and the assessment criteria. Students were required to analyse their proposals in relation to SDG 9 and SDG 12 (part-time students) or according to criteria they have set themselves (full-time students). In relation to SDG 9, they examined how automation modernizes production infrastructure and improves process stability and repeatability.

Part-time students assessed energy consumption per production cycle, the number of idle robot movements, trajectory length, and machine utilization rates. A central design objective was to demonstrate that maximizing productivity does not always align with minimizing environmental impact, and that multi-criteria trade-off analysis is a core engineering competence. Trajectory optimization - reducing energy consumption and peak power draw while maintaining output - was an explicit element of the project task.

Full-time students were allowed to freely choose suitable environmental criteria, as long as they ensured that at least two of them, they regarded as most important, were considered and applied - along with the other criteria - to each of the three separate concepts. Students were required to evaluate not only the technical and environmental feasibility of their solutions but also their social implications. The concept of responsible automation was also addressed by considering the future role of workers affected by the implementation of robotic technologies.

## 1.5 Methodologies and tools used (PBL structure, facilitation techniques, etc.)

The project was implemented using a Problem-Based Learning (PBL) structure in which student teams received an open-ended engineering challenge rather than an expected solution. Lecturer has provided baseline data (e.g. for full-time groups they were workpiece geometry, mass, process requirements, and reference cycle time for the manual process) and has defined the required deliverables and assessment criteria but did not prescribe the solution approach. Teams were responsible for all design decisions, including equipment selection, layout configuration, and variant comparison. The project included iterative design cycles supported by lecturer's feedback and milestone reviews. Students applied brainstorming techniques, stakeholder analysis, multi-criteria

assessment methods, agile-inspired project management principles, and iterative engineering design approaches to develop and refine their concepts.

Both groups of students (full-time and part-time) were using different computer software like ABB RobotStudio, FlexSim, Siemens NX, Autodesk Inventor and others.

The course design situated the lecturer concurrently in the roles of facilitator and mentor, while explicitly underscoring that project teams are responsible for autonomous decision-making and for independently organizing and allocating internal roles of participating students.

## 1.6 Organization of the project (group formation, timeline, milestones)

The project was organized as a team-based activity within a Project-Based Learning framework. It ran over 8 weeks with different number of contact hours (15 for full-time students and 9 for part-time group) within the spring semester 2026 (01.03.2026–19.06.2026) and involved 55 students distributed across three groups: one part-time group (28 students, 5 teams) and two full-time groups (27 students total, organized into 7 teams: 3 teams in one group and 4 teams in the other). Teams of 3–5 students were formed at the beginning of the project period. Each team was responsible for organizing its own workflow and distributing responsibilities (roles) like Project Manager, Designers, Researchers, Verifiers etc. Position names and areas of responsibility were set out in the team's contract.

In the case of the part-time group, due to the nature of the classes and the frequency of meetings, there were no strictly defined milestones, only informal consultations during classes and office hours

### 1.7 Deliverables requested from students (type, format, deadlines)

Each team was required to submit a comprehensive project report as a presentation in PDF or PPTX format, structured in accordance with the instructor's guidelines. The report, in the form of a presentation, was delivered by each team during the final session of the relevant didactic cycle. In addition to presenting their findings, each team responded to comments and questions raised by the tutor and fellow students – acting and behaving as potential investors. The discussion was intended as an exchange of views, rather than an assessment of the team's solution or presentation. Consequently, each report had to be ready no later than the day of the final session, and students were given an additional two days to correct any technical errors and upload their presentations to the Distance Learning Platform.

### 1.8 External collaborators involved (mentors, companies, experts...) and their role

No external collaborators were involved in this implementation.

## 2. Project Evaluation

### 2.1 Assessment criteria and methods used

Adjusting the assessment framework to suit a Project-Based Learning (PBL) format turned out to be a major challenge, because the original course syllabus had not been developed with this mode of delivery in mind. It was therefore essential to undertake a coordinated effort to systematically realign the existing assessment framework with the educational aims that form the foundation of problem-based learning (PBL).

As a first step, the established learning outcomes defined in the course syllabus were mapped onto a learning outcomes matrix grounded in the revised Bloom's

Taxonomy (Anderson & Krathwohl), resulting in a set of project-oriented learning outcomes. This mapping provided a structured foundation for the subsequent development of assessment tools.

Building on this matrix, a dedicated assessment rubric was constructed. The resulting rubric comprised seven criteria, each assigned an appropriate weight reflecting its relative importance within the project. Student performance against each criterion was evaluated on a four-point grading scale: 2 (insufficient), 3 (satisfactory), 4 (good), and 5 (very good).

Crucially, the criteria were designed to assess the overall quality and process of team collaboration rather than focusing narrowly on the correctness of the final solution. This approach reflected the fundamentally collaborative nature of the project, which placed greater emphasis on teamwork, problem-solving process, and shared responsibility than on individual knowledge verification alone.

## 2.2 Evidence of student learning (examples, outputs, results)

Project documentation, milestone deliverables, CAD materials, assessments, and presentation files were submitted and stored on the Distance Learning Platform of the Silesian University of Technology. The submitted materials document the complete design process, including stakeholder analysis, automation assessments, sustainability evaluations, robotic cell concepts, and final engineering solutions. Each team prepared either a final presentation or a detailed project report in presentation format, submitted as a PDF or PPTX file. The presentations provide both justification for the engineering decisions and specific calculation or simulation results.

The materials present independent concepts for robotized material-handling and machining workstations. They include descriptions of the processes and

input data, calculations supporting robot and gripper selection, alternative equipment layouts, robot workspace models, alternatively process points and trajectories, cycle-time and productivity analyses, assessments of environmental aspects, and final conclusions. The project documentation includes sketches, drawings and visualizations.

The files provide direct evidence of the achievement of the intended learning outcomes, including equipment selection, the design of robotized internal transport systems, assessment of concept feasibility and safety, and the integration of SDGs into engineering.

# 3. Reflections and Recommendations

## 3.1 Main achievements and strengths of the project

The project involved 55 students (28 part-time and 27 full-time students) working in teams. Each team developed an independent concept for automating and robotizing workpiece transport within a CNC machining cell. The projects addressed, among other applications, the machining of brake discs, steel shafts, pins, and plate-shaped components. The project workflow included the analysis of the manual process and input data, the selection of the robot, gripper, machine tool, and transport equipment, the design of the workstation layout, the definition of process points and robot trajectories, and the comparison of alternative variants in terms of cycle time, productivity, and environmental impact.

A significant strength of the project was the integration of design and organizational decisions with quantitative assessment criteria. The teams verified the required robot payload by considering the combined mass of the workpiece and gripper, assessed the robot's reach and access to the IN-CNC-OUT zones, and subsequently compared different variants, with particular

emphasis on the workpiece transport method. The solutions considered included dual grippers and automatic gripper exchange, the operation of one or two machine tools, conveyor-based transport, and the use of automated guided vehicles (AGVs). Different software was used primarily for concept visualization and verification.

The strongest educational outcomes were observed in the development of teamwork, responsibility, communication, and decision-making competences. Students successfully learned how to organize their work, assume project roles, and take responsibility for assigned tasks.

The project differed from traditional engineering courses by emphasizing self-organization, collaboration, and active participation in the decision-making process. Rather than following predefined instructions, students were required to develop and justify their own solutions.

A major strength of the proposed robotic cell concepts was the consideration of environmental impact, Sustainable Development Goals, and principles of responsible automation. Many teams explicitly considered how robotization could improve manufacturing processes while maintaining socially responsible approaches toward employees affected by automation initiatives. A particularly relevant outcome was the detailed trajectory optimization performed by one team. After modifying the motion speeds, increasing the path-blending zones, and adding an intermediate point for the robot's movement out of the machine tool, the total energy consumption per cycle decreased from approximately 2,000J to 1,590 J, while the peak instantaneous power decreased from approximately 2,016 W to 599 W. This result demonstrated that motion smoothness, trajectory geometry, and the reduction of abrupt acceleration changes may be as important as cycle-time reduction.

The project integrated technical considerations with sustainable development objectives. In relation to SDG, the students examined the modernization of production infrastructure, process automation, and improvements in process stability and repeatability. They considered the reduction of idle movements, shorter transport paths, lower energy consumption per cycle, fewer defective parts, and more efficient machine utilization. Teamwork also supported the development of competencies in task allocation, justification of engineering decisions, data analysis, and professional presentation of results.

## 3.2 Challenges faced and how they were addressed

One of the most frequent challenges was effective teamwork and coordination between team members. The students initially experienced difficulties in distributing responsibilities and coordinating project activities. These issues were addressed through role assignment, internal reviews, and regular discussions within teams. Each team had to work out the way to turn the general task requirements into a coherent technical concept. The teams had to simultaneously consider the mass of the workpiece and tooling, the required robot reach, access to the machine tool workspace, workpiece orientation, safe gripping conditions and collision-free movement between the process zones. This problem was addressed by calculating the minimum required payload with an appropriate safety margin, reviewing manufacturers' technical documentation, and modelling the robot workspace in a simulation environment.

Another challenge involved decision-making during the design process. Students frequently encountered situations that required trade-offs between technical performance, sustainability, safety, and practicality. Multi-criteria analysis methods were used to support objective evaluation and selection of alternatives. The environmental impact assessment also proved challenging due to the interdisciplinary nature of sustainability considerations. The students

addressed this issue by applying structured evaluation methods introduced during the course. This involved comparing variants that differed not only in equipment layout but also in cycle organisation and system complexity. A dual gripper reduced workpiece exchange time, while an automatic tool-changing system increased flexibility at the expense of additional robot movements. Similarly, the use of a second machine tool significantly increased productivity but also increased energy demand and costs. The teams prepared comparative assessments of cycle time, productivity, quality, cost, and environmental aspects. They subsequently justified the selection of the variant that best corresponded to the adopted priorities. Interpreting safety requirements, applying risk assessment principles, and transforming safety concepts into practical solutions posed further difficulties. These were addressed through consultations with lecturers, open discussion with the other teams, iterative design refinement, and the use of good practices in machine safety.

## 3.3 Lessons learned for future implementations

The project demonstrated the considerable educational value of Project-Based Learning structure in engineering education. Future implementations should continue to utilize self-organized teams, role assignment, and shared responsibility as fundamental elements of the learning process.

An important recommendation is to increase the amount of project time available to students. Grouping classes into longer project sessions (blocks) would enable teams to devote more time to collaborative work and technical discussions during scheduled meetings.

The project also highlighted the need to further adapt assessment procedures, written in syllabus, to the specific characteristics of Project-Based Learning. Greater alignment between grading criteria, expected learning effects and PBL

principles would better reflect the diverse competences developed throughout the project.

Future editions should continue to strengthen sustainability-oriented thinking and responsible automation concepts, ensuring that students understand both the technical and societal implications of implementing robotic technologies in modern manufacturing systems. Upcoming implementations could extend the project by validating the selected concept on a laboratory workstation or using a more comprehensive digital twin. Work in small teams with clearly defined roles should also be retained, as it facilitated the integration of competencies in robotics, machining technology, logistics, modelling, and sustainable production.

# 4. Supporting Material

## 4.1 Lecturers' materials and project documentation

Lecturers' materials and project documentation are available in the following link:

https://drive.google.com/drive/folders/1YI7869nzTB0GoskQaMguJMI6p1RTkwiZ?usp=drive_link

## 4.2 Deliverables produced by students, final presentations or pitch materials

An example of deliverables produced by students is available in the following link:

https://drive.google.com/drive/folders/1OushfjsNcTyRhjSr9pX34uoueJx4Ngc1?usp=drive_link

Students' final presentations are available in the following link:

https://drive.google.com/drive/folders/1W0btCONmRc7derhPqTyd9MH5dg9C_Nrz?usp=drive_link

## 4.3 Images/videos (with consent)

Photographic and video records were captured with the explicit consent of the participating students, and are available in the following link: https://drive.google.com/drive/folders/1zypNei7omAPRaYx1gJ1xE3SM0BJBqWJ6?usp=drive_link

## 4.4 Any other relevant material

All the materials, including this report, are available in the following link: https://drive.google.com/drive/folders/1j45J0ahUvku9JyXQxj-1hmg1HmUViRxX?usp=drive_link