ISBN: 978-3-95450-255-4 ISSN: 2226-0358 doi: 10.18429/JACoW-ICALEPCS2025-WECR001

DEVELOPMENT OF ACCELERATOR CONTROLS FOR FAIR – THE MANAGEMENT ASPECT

R. Baer[1], F. Ameil[1], J. Fitzek[1], Š. Šimec[2], G. Čuk[2]
[1]GSI Helmholtz Centre for Heavy Ion Research, Darmstadt, Germany
[2]Cosylab, Ljubljana, Slovenia

Abstract

As the works at FAIR (Facility for Antiproton and Ion Research) progress deeper into the installation and near the commissioning phase, FAIR control system gets closer to its final shape. With many software parts for the accelerator controls completed, valuable experience has been gained from the encountered managerial challenges.

In this paper, we present the best practices and lessons learned from tackling challenges in the scopes of managing contributions from in-kind partners, consortia and other contractors, project planning, establishing effective communication and coordination between in-house teams and outside partners, applying agile concepts, dealing with dynamics at FAIR and others.

THE FAIR PROJECT

The Facility for Antiproton and Ion Research (FAIR) is an international large-scale accelerator project currently under construction at GSI Darmstadt (Fig. 1) [1, 2] and progresses well towards commissioning [3]. Designed to provide unprecedented research opportunities in nuclear physics, atomic physics, plasma physics, and materials science, FAIR represents one of the most ambitious accelerator projects worldwide. When completed, the facility will comprise a complex chain of linear accelerators, synchrotrons, storage rings, and experimental stations, enabling a wide variety of high-intensity, high-quality beams for a broad international user community.

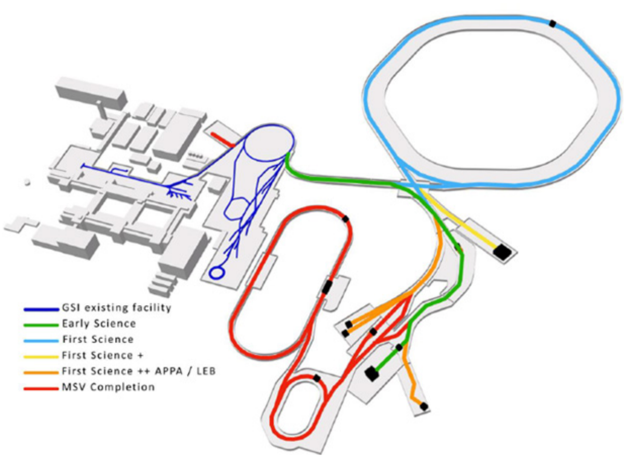

Figure 1: Overview over the existing GSI accelerator complex (in dark blue) and the new facilities of the FAIR project. The first project stage, "First Science+" is depicted in green, light blue and yellow.

FAIR is realized as an international collaboration, with nine founding shareholder countries, that signed the international agreement in 2010 plus more partners as of today. Contributions to FAIR are provided predominantly in the form of in-kind deliverables. This model requires partner institutions and countries to take responsibility for the design, construction, and delivery of well-defined subsystems, rather than contributing purely financial resources. While this approach leverages the expertise and resources of many partners, it also introduces unique challenges. Chief among them is the necessity to define a fixed scope for each in-kind contribution early in the project, years ahead of a detailed design process and implementation or production of components. Once agreed, changes are difficult to implement, and therefore careful planning, strong communication, and well-established interfaces are essential.

The in-kind model also depends on a trilateral legal arrangement between the international *FAIR organization*, the contributing *provider*, and the national *shareholder* representing the partner country. This arrangement relies heavily on the goodwill, goal orientation, and constructive cooperation of all parties involved. Only by maintaining a careful balance between technical requirements, partner capabilities, and project objectives can such a large-scale collaboration succeed.

DEVELOPMENT OF THE CONTROL SYSTEM FOR FAIR

The Accelerator Control System (ACS) for FAIR is being realized as a main in-kind contribution from GSI, the host laboratory (also providing the existing accelerator injector chain) and two partner countries Slovenia and recently Poland. This arrangement was confirmed by the relevant international advisory bodies, which recognized that GSI must retain responsibility for the architecture and technology stack. Maintaining this responsibility ensures that the host laboratory preserves the necessary technical expertise to operate, adapt, and further develop the Control System throughout the lifetime of the FAIR facility.

Concluding in-kind agreements is the result of years of intense technical and organizational preparations. For example, the collective in-kind agreement of GSI as host lab with FAIR was not formally concluded until 2016, even though GSI's role had already been defined and established years earlier. The in-kind contract with Slovenia, which includes substantial contributions to the accelerator control system and beam diagnostics systems, was already signed in 2014, also after several years of preparation. The provider is the Tehnodrom consortium, which is led by Cosylab [4] and Instrumentation Technologies [5], both well established companies in the accelerator community, and

ISBN: 978-3-95450-255-4 ISSN: 2226-0358 doi: 10.18429/JACoW-ICALEPCS2025-WECR001

comprises several other Slovenian companies as well. Finally, in 2023 Poland extended its in-kind contract with FAIR by also engaging in a contribution to the accelerator control system; in-kind Provider is the company S2Innovation [6].

From a management perspective, this in-kind model requires careful planning and resource coordination. Unlike hardware components that can be clearly specified, delivered, and integrated, a software-based in-kind contribution spans the entire duration of the project. Development must align with evolving technical requirements, facility construction milestones, and feedback from early operational use. Consequently, the project plan emphasizes an incremental rollout strategy: new subsystems of the Control System are deployed and validated in the existing GSI facility as soon as possible, allowing early testing with beam and reducing risks for later full-scale deployment.

This approach began with the CRYRING experimental storage ring in 2015 as a testbed for the new system, before extending to the SIS18 synchrotron, the experimental storage ring ESR, and the high-energy transfer lines. Each step provided valuable feedback from operators and machine experts, which in turn caused adjustments to the system architecture. The final stage of this rollout is the replacement of the legacy control system for the entire linear accelerator UNILAC injector chain which is currently being implemented. By 2026, all accelerators will be operated exclusively with the new Accelerator Control System, marking the completion of the transition.

Project planning for controls at FAIR must therefore balance two objectives: on the one hand, the reliable replacement of the legacy system across the existing facility while at the same time providing robust operation for experimental beam times, and on the other, the timely delivery of the new capabilities required for FAIR commissioning and experiments. This dual responsibility places high demands on resource allocation, scheduling, and long-term maintainability. Coordinating these activities within the framework of an in-kind contribution highlights the unique management challenges of software-intensive deliverables in large-scale international research projects.

This paper mainly refers to in-kind experiences with the Slovenian contribution, as the Polish contribution has only recently been added.

SLOVENIAN IN-KIND CONTRIBUTION SCOPE AND MILESTONES

The Slovenian in-kind contribution to the FAIR Control System covers a broad scope, extending beyond software development to include hardware and electronics (see Table 1). This encompasses industrial control systems with electrical design and production of cabinets with industrial control components as well as the design and delivery of electronic boards, most notably timing receiver boards that form a key component of FAIR's timing system infrastructure.

In general, the approach of defining the in-kind software work packages in such a way that they represent largely complete subsystems with well-defined technical interfaces to the core control system proved to be effective. This ensured that no expert knowledge of the underlying system functionalities and paradigms was required. Examples include subsystems such as alarms, diagnostic logging, and archiving. Likewise, the software integration of a wide variety of equipment via the front-end framework FESA was very well suited as an in-kind contribution as well, even though the functionality and the definition of interfaces had not yet been finalized at the time the in-kind contract was concluded.

At the outset, the specification for this in-kind contribution was defined on a high level, reflecting both the complexity and long-term nature of the FAIR project. Managing such a contract under the framework of fixed scope and fixed price, but with an undefined project duration, posed a particular challenge. Successful execution required a high degree of mutual understanding and flexibility from all stakeholders, including FAIR, the Slovenian provider, and the national shareholder.

Historical Milestones:

- **Preparation Phase**: Extensive preparatory work was required to define the technical scope and contractual framework, ensuring alignment with FAIR's overall architecture.
- **2014 - Contract Signing**: The in-kind contract with Slovenia was formally concluded in 2014, with the Tehnodrom consortium selected as the executing industrial partner. This marked the official start of Slovenia's contribution to FAIR.
- **2019 - Amendment to the contract**: The contract between the provider and the shareholder was realized with fixed dates ending in 2018. Because of overall delays in the FAIR project and related costs increase, an amendment had to be added to the in-kind contract. In addition, with this amendment, some work-packages which were put on hold or dropped during the project execution were officially descoped.
- **2025 - Contract Completion**: The original in-kind contract is scheduled for completion in August 2025. An official closing event will be held on October 21, 2025, in Ljubljana, marking the successful conclusion of Slovenia's first major in-kind contribution to the FAIR project.

IN-KIND COLLABORATION: GSI POINT OF VIEW

The Slovenian in-kind contribution to the FAIR Control System illustrates both the opportunities and the challenges of long-term international collaboration within the FAIR framework. The contract was defined at a high level and signed early in the FAIR project. As a result, there was a considerable time gap between the specification of work packages and the actual start of implementation. During this time, technical requirements evolved, and project priorities shifted. Some work packages were underestimated in complexity, while others became obsolete or had to be de-prioritized in favour of new developments.

ISBN: 978-3-95450-255-4 ISSN: 2226-0358 doi: 10.18429/JACoW-ICALEPCS2025-WECR001

Table 1: List of Slovenian in-kind ACS contribution work packages with completion dates (not comprehensive)

Work package	Status	Date
Alarm system	completed	05/2018
Diagnostic logging system	completed	02/2015
Archiving system	completed	08/2020
Soft Oscilloscope System	descoped	09/2019
Stepper motor control FESA	completed	02/2015
Control system for p-linac RF	completed	08/2022
Control system for ring BPMs	completed	08/2018
Control syst. for HEBT BPMs	completed	04/2021
Pneumatic drives	descoped	09/2019
Timing receivers PMC/AMC	completed	12/2019
Timing receivers VME	descoped	09/2019
Stepping motor controllers	completed	07/2018
Vacuum control system	completed	06/2025
Interlock system	completed	03/2016
Beam transm. monitor system	completed	08/2022
Post mortem system	descoped	09/2019

Ingredients for Success

Managing such dynamics required a flexible and pragmatic approach from both sides. Several key elements proved essential for successful collaboration:

- **Trusted and Established Partnerships**: Carefully chosen partners with strong pre-existing business relationships, well established in the community, and with a solid background in similar technical and organisational environments.
- **Local Liaison**: In the early phase, having a dedicated liaison person from the partner working on-site at the GSI campus facilitated direct communication, mutual understanding, and faster problem resolution.
- **Flexibility**: Both partners accepted that the original scope would need adjustments. Flexibility in re-allocating resources, redefining deliverables, and adjusting schedules was crucial to keep the project on track.
- **Regular Coordination**: Structured coordination was maintained through regular steering meetings. These were held on a bi-weekly basis, and during critical project phases even weekly, providing a forum for transparent discussion of progress, risks, and open issues.

Working Modes and Lessons Learned

A decisive factor for success was the choice of working modes. Collaboration was organized to minimize administrative overhead and emphasize technical progress:

- **Direct Technical Interaction**: Joint teams were formed where engineers from the Slovenian partner and GSI developers worked closely together. Direct interaction between technical experts reduced delays and misunderstandings.
- **Operational Focus**: While the contract provided the formal framework, the day-to-day collaboration concentrated on operational and technical problem solving rather than contractual details. This approach fostered trust and mutual ownership of results.
- **Adaptability**: By acknowledging early that priorities could shift, both sides were able to adapt work packages to evolving needs without jeopardizing the overall contribution.

IN-KIND COLLABORATION: COSYLAB POINT OF VIEW

Developing control systems for complex machines presents challenges, including loosely defined requirements and shifting timelines and priorities. Successful collaboration requires all partners to be able to adapt, which can take a considerable amount of effort.

Cooperation

To maximize knowledge transfer, avoid misalignment, and deliver effectively and on time, Cosylab and GSI engineers cooperated closely throughout the project lifecycle:

- **Planning**: Plans were developed jointly to incorporate perspectives from both organizations.
- **Requirement Engineering**: For high-level or loosely defined requirements, the teams produced a reliable set of detailed requirements and baselines together.
- **System Design**: Where complexity required deeper analysis, the design documents were written based on joint studies combining system knowledge and technical expertise.
- **Software Development**: A shared code repository and regular code reviews maintained high codebase awareness and code quality.
- **Hardware Production**: In case of delayed HW components, Cosylab were able to borrow the required components from GSI.
- **FAT & SAT**: The tools and environment prepared for Factory Acceptance Testing (FAT) were shared to facilitate their reuse during Site Acceptance Testing (SAT). SATs were executed jointly.

Flexibility

To be able to offer the required flexibility, the following proved to be valuable:

- **Agile Approach**: Focus towards reaching MVPs and production of early demos enabled quicker alignment between stakeholders as well as testing and validating functionality with end-users early in the development process.
- **Resource Planning**: Projects often required a mixed set of expertise, thus having engineers with varied skillset available proved to be necessary. Personnel schedules needed to have flexibility included to absorb potential project changes as well.

ISBN: 978-3-95450-255-4 ISSN: 2226-0358 doi: 10.18429/JACoW-ICALEPCS2025-WECR001

- **Project Planning**: Bi-weekly project budget reports were produced and steering meetings held to make adjustments. Multiple projects were run in parallel to cover cases when one might stall or priorities shifted.
- **On-site Presence**: Substantial on-site work, especially during the early and late project stages, enabled smoother onboarding and acceptance testing.
- **Testing facilities**: Test hardware and equipment were shipped to be used on Cosylab premises and remote test setups were made available by GSI.

PROJECT MANAGEMENT APPROACH

Project planning for the FAIR Control System has been shaped by the unique challenges of developing a large-scale international accelerator facility. From the outset, specifications for the Control System were written very early in the FAIR project, long before actual implementation began. Consequently, no specification could be considered perfect or even fully complete, and all requirements needed continuous review and revision to remain aligned with technical realities, evolving priorities and results from early beam operation of system components after deploying in the already existing GSI facility.

To address these challenges, a hybrid project management approach has been adopted. At the overall FAIR project level, a traditional waterfall methodology has guided the definition of the project scope, milestone planning, and the staged realization of accelerator components. This ensured clarity in contractual agreements, funding, and high-level scheduling.

However, at the implementation level for the Control System, a more agile approach has proven essential. Iterative development cycles, frequent testing in the integration environment, and early validation with beam allowed the team to adapt to technical changes, refine requirements, and deliver working subsystems incrementally. This has enabled early detection of design or interface issues, reduced risk during full deployment, and fostered continuous learning and adaptation within the project team. The hybrid approach has combined the stability of long-term planning with the flexibility required for the fast-evolving technical and operational environment of FAIR.

In summary, the hybrid project management approach—combining traditional long-term planning with iterative, agile execution—has been key to successfully navigating the technical and organizational complexity of the FAIR Control System.

PROJECT ORGANIZATION

To realize the FAIR project, the accelerator division at GSI was largely reorganized into a dedicated project-based structure. The Controls Department, like most other technical departments, was assigned to a corresponding project division to emphasize the priority of FAIR, even though significant resources continued to be allocated to upgrading and operating the existing accelerator facilities. Like all development and procurement activities at FAIR, the complex tasks of development and implementation of the control system was broken down in 12 work packages into manageable units. During project execution, the role of *work package leader* is therefore critical for delivering on schedule, budget, and performance goals while ensuring smooth collaboration between diverse teams. Now, with commissioning approaching, the organization is gradually transitioning back to a classic operations-oriented structure in preparation for FAIR operations.

Setting Priorities

As FAIR becomes increasingly integrated into the existing accelerator complex, it has become evident that much closer coordination between control system specialists, machine experts, and accelerator physicists is required. With the project's progression and the imminent start of commissioning, priority alignment has become critical. Essential modernization and upgrade activities – such as the replacement of the legacy UNILAC injector control system, the last remaining accelerator to migrate to the new FAIR control system [7, 8] – must be balanced against the demands of ongoing accelerator operations and preparations for FAIR commissioning within the constraints of limited resources.

To ensure that all required functionalities are available at the start of FAIR commissioning and for the relocation of Operation to the new fully digital FAIR Control Centre presently under construction in 2026, a Controls Steering Group was established in 2023. Based on an extensive analysis of requirements and controls feature needs, priorities aligned to the overall GSI/FAIR objectives have been defined to address the restricted time and resources situation. Project milestones and progress is continuously being monitored at high-level, steering actions defined if needed.

At the operational level, each software application is assigned a dedicated product owner, typically from the operations department. The product owner is responsible for defining requirements, communicating with stakeholders, and managing hundreds – sometimes over a thousand – detailed requirements for a single product. Acting as the primary liaison with developers and following an agile approach, the product owner sets priorities for upcoming milestones and plans deliverables for each iteration. Regular meetings provide a forum for product owners to share experiences and address requirements that span multiple products. This approach has proven highly effective in practice, though it requires a significant investment of resources from the product owner.

Strategic Milestones and Detailed Requirements

One of the central challenges in large-scale software development is maintaining alignment between the vast number of detailed requirements and the high-level milestones defined at the strategic level, in this case by the Controls Steering Group. While product owners manage a huge number of requirements on an operational level, ensuring that these granular tasks meaningfully contribute to overarching program objectives is far from straightforward.

The difficulty arises because operational requirements are often defined in very specific and technical terms,

ISBN: 978-3-95450-255-4 ISSN: 2226-0358 doi: 10.18429/JACoW-ICALEPCS2025-WECR001

whereas strategic milestones are formulated in a more abstract, outcome-oriented language. This discrepancy creates a translation gap: stakeholders at the strategic level need to understand progress in terms of milestone readiness, while developers and product owners think in terms of deliverables, iterations, and backlog items. Bridging this gap requires not only careful mapping of requirements to milestones but also robust reporting mechanisms that can aggregate and visualize progress across multiple products and teams.

At present, reporting mechanisms are undergoing a revision to address these challenges. The aim is to create mechanisms that allow stakeholders at all levels to gain a clear overview of readiness with respect to upcoming milestones. Such mechanisms must be able to capture the complexity of dependencies between requirements, while at the same time providing a simplified and comprehensible representation of progress for decision-making. In doing so, they can enhance transparency, improve coordination across teams, and ultimately ensure that strategic goals remain on track despite the complexity of the underlying operational requirements.

PROJECT CHALLENGE: DESCOPING

One of the key challenges in the FAIR Control System project has been descoping, a consequence of changes in the overall FAIR project scope and realization strategy. Initially, FAIR was planned with a full scope covering all experimental stations and accelerators (see Fig. 1). Over time, the project was staged, moving from the original full facility vision (Full FAIR) to the Modularized Start Version (MSV), and finally focusing on the stages Early Science (ES), First Science (FS), and First Science Plus (FS+). These changes had a direct impact on control system work packages and their implementation.

As a result of descoping, certain components and subsystems were deprioritized or required revision. For example, the p-Linac, with its full control system implementation, was deprioritized, and the vacuum control system – including the delivery of all control cabinets – needed to be redesigned to match the reduced project scope. At the same time, cost increases for specific components required careful balancing and flexible handling of deliverables, ensuring that resources were allocated efficiently without compromising critical functionality.

Despite these adjustments, the development of the central Control System remained largely unaffected. Most of the software, services, and generic applications are essential for the operation of all accelerators. Consequently, descoping had limited impact on these general deliverables, allowing the core Control System functionality to proceed according to plan.

Overall, the FAIR experience demonstrates that large-scale accelerator projects must maintain a flexible approach to deliverables, enabling adaptation to changing project scope while preserving the integrity and functionality of central systems.

CHALLENGE: COVID-19 PANDEMIC

The COVID-19 pandemic posed additional challenges to the development of the FAIR Control System, particularly in coordinating international in-kind contributions. However, the situation also accelerated the adoption of online collaboration tools, which have since become standard practice within the project. With the evolution of video conferencing technologies, it became much easier for teams to maintain continuous communication, whether working remotely or on-site. In many cases, dedicated video conference rooms or permanent virtual meeting channels were established, enabling real-time coordination across teams (of course, being in the same time zone helps also). The relatively small number of partners further facilitated this mode of collaboration. Overall, the pandemic underscored the value of robust digital collaboration infrastructure for the successful execution of international in-kind contributions.

SUMMARY

The Slovenian in-kind contribution to FAIR stands as a representative example of how smaller partner nations can make targeted, high-value contributions to large international research infrastructures. By combining software development with specialized hardware and electronics delivery, Slovenia has contributed essential components to the FAIR Control System while demonstrating the effectiveness of the in-kind model when guided by jointly developed objectives, technical expertise, and sustained commitment – even when these objectives were still evolving. Although the in-kind model has its challenges, flexible and collaborative working practices – such as deploying representatives on-site to establish a work package – proved particularly valuable.

The collaboration with Slovenia demonstrates that in-kind contributions in complex software and electronics projects cannot be managed by contractual specification alone. Success depends on building effective joint teams, maintaining regular and transparent communication, and keeping technical overhead low. These lessons provide a model for future collaborations with industrial and international partners within FAIR.

FAIR benefited from a limited number of contributions of substantial size and from carefully chosen partners with long-standing, trusted business relationships. This combination reduced coordination overhead and allowed the project to maintain progress even under restrictive conditions. For a complex accelerator project, partners with prior experience in accelerator operations or large-scale physics control systems are highly advantageous. Familiarity with complex technical environments reduces the learning curve, limits the overhead associated with onboarding, and allows teams to contribute effectively from the outset. In contrast, enabling new partners without such experience can require substantial time and resources, a challenge that is magnified under conditions that limit in-person interactions.

ISBN: 978-3-95450-255-4 ISSN: 2226-0358 doi: 10.18429/JACoW-ICALEPCS2025-WECR001

REFERENCES

[1] P. J. Spiller *et al.*, "Status of the FAIR Project", in *Proc. IPAC'18*, Vancouver, Canada, Apr.-May 2018, pp. 63-68. doi:10.18429/JACoW-IPAC2018-MOZGBF2

[2] J. Blaurock, H. Simon, O. Boine-Frankenheim, and P. Spiller, "FAIR completion of construction works, towards commissioning and first science", in *Proc. IPAC'23*, Venice, Italy, May 2023, pp. 3923-3927. doi:10.18429/JACoW-IPAC2023-THYD1

[3] S. Reimann *et al.*, "FAIR Commissioning – Towards First Science", presented at the IPAC'25, Taipei, Taiwan, Jun. 2025, paper THBN2, unpublished.

[4] Cosylab, https://www.cosylab.com

[5] Instrumentation Technologies, https://www.i-tech.si/.

[6] S2Innovation, https://www.s2innovation.com

[7] P. Gerhard, "About the New Linear Accelerator Control System at GSI", in *Proc. ICALEPCS'23*, Cape Town, South Africa, Oct. 2023, pp. 529-533. doi:10.18429/JACoW-ICALEPCS2023-TUPDP018

[8] H. Hüther, J. Fitzek, *et al.* "Supporting injector operation with the FAIR Settings Management System", presented at ICALEPCS'25, Chicago, IL, USA, Oct. 2025, paper TUPD023, this conference.