Review of the Application for Habilitation of Dr. Tamás Ruppert (Human-centered Manufacturing Systems)

1 Background and Overall Assessment

I was invited by the Doctoral and Habilitation Council of the Doctoral School of Information Technology (University of Pannonia) to provide an external review of the habilitation application of Dr. Tamás Ruppert. The purpose of this review is to assess (i) whether the scientific achievements and professional record of the candidate justify the award of the *Habilitated Doctor* title, (ii) whether the application is sufficiently mature to proceed to the public phase of the habilitation procedure, and (iii) whether, following a successful public phase, the award of the habilitation title is recommended. The review is prepared in English in line with the announced English-language component of the public defence.

Dr. Tamás Ruppert is an associate professor at the Faculty of Engineering of the University of Pannonia and serves as Head of the Department within the Institute of Systems Engineering. He obtained his PhD degree in June 2020. In his self-report, he positions his work at the intersection of modern manufacturing systems, industrial digitalization, and artificial intelligence, with a clear emphasis on human-in-the-loop operation in the transition from Industry 4.0 to Industry 5.0. The candidate reports that he established an Industry 5.0 laboratory at the University of Pannonia to support sensor- and algorithm-driven research on human-centered manufacturing.

The topic of the habilitation thesis, *human-centered manufacturing systems* (Operator 4.0 / Industry 5.0), is timely and highly relevant. Current manufacturing systems increasingly require (a) flexible collaboration between humans and automated or semi-automated equipment, (b) data-driven decision support, and (c) explicit consideration of human factors such as workload, cognitive state, ergonomics, safety, and training. The candidate's framing is well aligned with contemporary directions of industrial AI and cyber-physical production systems: it connects sensing and data acquisition, machine learning-based inference (e.g., activity recognition), semantic/structured representations (e.g., knowledge graphs), and the integration of these components into decision support and digital twin concepts.

Regarding scientific performance indicators, the application presents a strong quantitative snapshot: H-index 18 (independent MTMT Hirsch index), total citations on the order of $\sim$ 1,200+, and a large body of publications (87 total, with 37 IF-indexed papers). The candidate also lists multiple high-quality journal outputs, including D1 and Q1/Q2 venues, and provides documentation of research organization activity (projects, professional service, and academic visibility). These parameters indicate a sustained and visible research activity that is consistent with habilitation-level expectations.

Overall, I am **very satisfied** with the scientific and academic quality of the submitted habilitation application. The material is well structured, the research programme is coherent and timely, and the publication and citation record demonstrates sustained international visibility. The application convincingly supports that the candidate has reached the level

of scientific independence and academic maturity expected from a habilitation applicant. Consequently, my assessment is strongly supportive both regarding entering the public phase and, following a successful public phase, regarding awarding the habilitated doctor title.

2 Scientific contribution

The scientific contributions form a coherent research programme rather than a collection of disconnected results. The work follows a clear end-to-end logic: *(i) measuring human activity and state in manufacturing environments, (ii) modelling and representing human-centered information in a structured and interoperable way, and (iii) using these models and measurements to support evaluation and decision-making in human–machine collaboration.* A central integrative concept of the application is the *Intelligent Collaborative Manufacturing Space (ICMS)* framework, which aims to provide a structured basis for sensor-driven collaboration between human workers and automated production assets.

Contribution A: Human-centered performance evaluation based on operational data. A major component of the thesis focuses on objective, data-driven evaluation of human work in production settings. The candidate builds on real-time locating systems / indoor positioning (RTLS/IPS) and complements these signals with approaches for visual-data-based activity recognition. The overall scientific value of this direction is that it connects raw operational measurements to interpretable and actionable indicators of performance and workflow behaviour. In particular, RTLS/IPS traces are leveraged to reconstruct and assess movement patterns and task execution, while machine learning methods are applied for recognizing and classifying activities from visual or sensor-based observations.

In my opinion, the strength of this contribution lies in (i) the practical relevance and deployability of the sensing modalities, (ii) the explicit link to manufacturing management use cases (monitoring, lean analysis, cycle-time control, and related operational decisions), and (iii) the attempt to integrate multiple data sources to improve inference quality. The research direction is credible and addresses a well-known gap: traditional manufacturing analytics often neglects fine-grained operator dynamics or treats them as unobserved noise, while the proposed approach makes these dynamics measurable and analysable.

Contribution B: Human-centered digital models and structured representations. A second key contribution is the development and use of human-centered digital models that enable integration of human-related information into manufacturing cyber-physical systems and digital twins. The candidate proposes a *Human-Asset Administration Shell (HAAS)* model to represent physiological parameters and derived human-centered factors (e.g., cognitive load and stress level) in a structured form. In addition, the work argues for the usefulness of *human-centered knowledge graphs* for modelling human behaviour and for supporting interoperability across the production IT stack.

This part is particularly important for habilitation-level assessment because it demonstrates system-level thinking. The candidate does not stop at data collection and local inference; instead, he addresses the integration question: how human-related information can be represented, updated, and consumed by other components of an industrial architecture. The HAAS and knowledge-graph directions provide a reasonable answer to this, and they are aligned with broader trends in semantic manufacturing and digital twin development. The novelty here is best interpreted as *domain-anchored integration*: applying semantic and structured modelling approaches in a human-centered manufacturing context, with concrete links to measurable operator-related variables.

Contribution C: Human-centered indicators using physiological and cognitive parameters. A third contribution addresses the assessment of latent and difficult-to-measure human states during task execution, with a focus on cognitive load and work instruction evaluation. The thesis reports laboratory experimentation and the application of wearable sensing to demonstrate the feasibility of extracting physiological signals and mapping them to meaningful indicators that can support production-related decisions. This direction is strongly aligned with Industry 5.0 priorities, where the human operator is not only a resource but also a central stakeholder, and where productivity objectives are jointly optimized with well-being and sustainability considerations.

Scientifically, this contribution is valuable because it extends manufacturing analytics beyond classical KPIs toward human-centric indicators. It also opens the door for more principled design and evaluation of work instructions and task configurations, which can have direct effects on safety, error rates, training time, and overall operational effectiveness.

Integration as a programme-level contribution: ICMS. The ICMS framework serves as an overarching structure that integrates sensing, modelling, and decision support into a single conceptual pipeline. The candidate positions ICMS as an "intelligent workspace" composed of four main functional spaces (work, observation, modelling, decision) that together enable real-time, observation-driven control and safer, more precise collaboration between humans and machines. In my assessment, the ICMS framework is a meaningful programme-level contribution because it provides a unifying reference model that connects the candidate's thesis groups. The strongest interpretive claim for ICMS is that it enables systematic end-to-end design and validation: from the definition of what is measured, through how it is represented, to how it is used.

Scientific maturity and positioning. Overall, the scientific programme is coherent, timely, and methodologically aligned with modern industrial AI. The publication record and scientometric indicators demonstrate substantial activity and international visibility. The candidate's work is strongly application-driven, which is appropriate for the field; at the same time, it includes conceptual and modelling elements (HAAS, knowledge graphs, ICMS) that go beyond case-by-case engineering.

For the public phase, it would be beneficial if the candidate presents the novelty and the scope of applicability in a *clearer and more concise* way, including (i) a brief and explicit summary of what is fundamentally new in the ICMS/HAAS/knowledge-graph integration and in the proposed indicator pipeline, (ii) a compact overview of the validation design and evidence base (settings, baselines, and the intended generalization claims), and (iii) a short, forward-looking perspective on industrial adoption (interoperability, data governance, privacy, and practical constraints). These points would further strengthen an already convincing and high-quality submission.

3 Teaching and academic maturity

The candidate reports a continuous teaching activity at the University of Pannonia since 2017, including 17 actively taught semesters. The documentation lists a broad teaching portfolio across engineering and data-oriented programmes, including courses in control, process management, data processing and programming, digital twin and process simulation, process modelling and process mining, and production intelligence. The reported contact hours are substantial, including a large volume of lecture hours, and the candidate reports extensive supervision activity (numerous BSc/MSc theses, TDK mentoring).

In addition to teaching volume, the candidate demonstrates academic maturity through programme-building activities: responsibility for specialised programmes (including Industry 4.0/5.0 oriented professional engineering training), laboratory establishment, and supervision/mentorship at doctoral level. The candidate also indicates active PhD supervision across multiple doctoral schools. Taken together, the teaching record and the reported mentorship and leadership activities meet the expected standard of habilitation, where the candidate must be able to represent an independent academic profile in education, supervision, and research community contributions.

4 Compliance with institutional expectations and documentation

The application is submitted in a structured, single compiled document with a table of contents and includes the key elements typically required for habilitation evaluation: request for procedure, acceptance by the doctoral school, CV, publication list, statements on meeting requirements, documentation of teaching activity, self-evaluation, scientometric indicators, and thesis statements in Hungarian (and the thesis structure indicates the presence of an English thesis section as well). The candidate also proposes topics for the public teaching lecture and provides the title for the scientific colloquium. Based on the materials provided, the documentation appears complete and appropriately organised for review.

5 Recommendations

Based on the presented scientific achievements, the coherent and timely research programme, the quantitative indicators of research output and visibility, and the documented teaching and academic maturity, **I strongly support that the habilitation procedure proceeds to the public phase.** Furthermore, **provided that the candidate completes the public phase successfully, I strongly recommend awarding the title of Habilitated Doctor to Dr. Tamás Ruppert.**

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