IMIC: Intelligent Manufacturing International Contest - towards the gradual design of a new benchmark

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Abstract Intelligent manufacturing control is a broad research domain at the center of the development of new industrial systems. Due to the focus on flexibility and reactivity of organizations, the control architectures must evolve accordingly. Therefore, several research trends have emerged, based on various paradigms: industrial agents, operational research, holonic manufacturing systems, among others. Due to their industrial roots, these research efforts are usually evaluated with regard to data and case studies directly extracted from specific industrial contexts. Over the years, this situation has perpetuated, and no actual benchmark exists that enables research teams to evaluate the performance of their proposals on real industrial case studies. This work intends to contribute to the creation of such a benchmark and, to do so, proposes organizing the first world contest on Intelligent Manufacturing Control. Each year, one previously studied case study will be expanded to create different instances to be tested by the contestants. These cases will be added to the global benchmark over the years, together with the best solutions provided by the contestants, in order to build the benchmark used to evaluate future research works.

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1 Motivations

In the field of Intelligent Manufacturing, the development and implementation of advanced control algorithms and architectures are rapidly evolving. Despite significant consideration, there remains a pressing need for standardized benchmarks that can facilitate consistent evaluation and comparison of the methodologies and technologies developed within the community, with an important side effect on education[1] and training [Breitinger et al., 2022]. This need is driven by the complexities and diversity inherent in manufacturing processes, which often necessitate tailored solutions that can be difficult to assess without a common framework [Oztemel and Gursev, 2020].

There is a lack of a suitable, comprehensive, and standardized benchmark for problems related to real industrial cases and complex systems in smart manufacturing [Pinquié et al., 2022]. Establishing such benchmarks is pivotal for the progression of intelligent manufacturing systems and for evaluating their evolution and performance. Therefore, it is necessary to propose this initiative at both national and international levels. To our knowledge, the Bench4Star initiative [Trentesaux et al., 2013] is the sole initiative that proposes a benchmark focusing on flexible job-shop problems with dynamic perturbations. For this reason, Bench4Star is a significant contribution and should be considered in this proposal. However, the Bench4Star initiative is based on a single, unchanging industrial system, which limits the diversity of industrial systems that are typically encountered in real life. Moreover, this initiative did not lead to a complete and usable benchmark, likely because of the complexity arising when progressively completing a benchmark.

Indeed, the creation of a comprehensive benchmark for Intelligent Manufacturing is a significant challenge. Constructing a benchmark ”from scratch” is a complex and resource-intensive endeavor. It requires extensive collaboration among industry experts, researchers, and stakeholders to ensure that the benchmark is relevant and adaptable to the dynamic nature of manufacturing technologies. Additionally, the benchmark should be representative enough to accommodate the myriad of variables and scenarios encountered in real-world applications, which further complicates its development. Industrial inspirations (such as the one presented in this article) or learning factory-based cases (such as [Erol et al., 2016] or [Borangiu et al., 2022] for example) can both be considered.

Given these challenges, this document outlines an innovative approach that involves progressively building the benchmark (or multiple ones) through an international contest. By creating and refining the benchmark year after year, we can leverage the collective expertise and feedback from the community to ensure its continual improvement and relevance. This iterative process should also allow the incorporation of new insights and industrial concerns, thereby maintaining the benchmark’s applicability and usefulness over time.

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[1] See for example the IMS² winter school (http://ims2.cran.univ-lorraine.fr/index.php/node/54) or the annual International Summer School on Industrial Agents ISSIA (https://issia-23.sciencesconf.org/)

To encourage early adoption and active participation from the community, an annual contest centered around a new problem, later introduced in the benchmark, is proposed. These challenges would not only stimulate interest and engagement but also provide valuable opportunities for researchers and practitioners to test and validate their approaches in a competitive and collaborative environment. This approach ensures that the benchmarks are continually updated and refined, reflecting the latest advancements in technology and industry practices. It also fosters collaboration between researchers and practitioners, leveraging their combined expertise to address complex industrial challenges. Ultimately, this initiative aims to drive continuous improvement and innovation in smart manufacturing, ensuring that the benchmarks developed remain relevant and effective in improving performance and competitiveness. The challenge would serve as a practical platform for demonstrating the benchmark's utility and for fostering a culture of continuous improvement and innovation within the community.

The main idea of this contest is to annually propose a new theme that addresses a real industrial case relevant to the interests of the SOHOMA community. Each theme will focus on intelligent manufacturing and present a problem specifically selected to align with the scientific tools and methodologies developed by our community, which include researchers and practitioners. In doing so, the contest will facilitate the development of benchmarks that are both scientifically rigorous and practically applicable to real-world industrial scenarios and complex systems.

This contest is a French initiative, driven by the IMS² working group [2]. The group of authors of this article constitutes the main core of the steering committee during this first year. International experts from academia and industry are more than welcome to integrate the steering committee of this contest, and will be invited in the first few months of the action to join. With these objectives in mind, and to maximize the impact and reach of this initiative, we suggest here coupling the annual challenge with the SOHOMA (International Workshop on Service-Oriented, Holonic and Multi-Agent Manufacturing Systems for Industry of the Future) workshop, in order to reach a broader network of experts and stakeholders. The SOHOMA workshop, known for its focus on service-oriented and agent-based approaches in manufacturing, provides an ideal venue to introduce and discuss the benchmark. This international collaboration would not only enhance the benchmark's credibility and adoption but also facilitate cross-pollination of ideas and best practices from diverse perspectives, as well as the dissemination of the early results each year during the workshop in dedicated sessions.

[2] IMS² is a french scientific community working on intelligent manufacturing systems and services. A description (in French) of the working group can be found at `http://ims2.cran.univ-lorraine.fr/`

2 The contest

2.1 Ambition of the contest

The competition aims to address the critical need for comprehensive, standardized benchmarks within our community and the broader field of smart manufacturing. This international contest will bring together researchers and practitioners in our community to collaboratively develop and refine benchmarks for intelligent manufacturing systems. By focusing on real industrial cases and complex systems, the competition will catalyze innovation and drive continuous improvement in smart manufacturing. This competition represents a strategic initiative to bridge the gap in benchmarking for smart manufacturing. By fostering collaboration and innovation, it will play a crucial role in advancing intelligent manufacturing systems, ensuring that they are well-equipped to meet the challenges of modern industrial environments. The objectives of this contest can be summarized as follows:

- Develop scientifically rigorous and practically applicable benchmarks for real-world cases and complex systems that can be used to assess and enhance the performance of intelligent manufacturing systems.
- Encourage collaboration between researchers and practitioners to leverage their combined expertise in tackling complex industrial challenges.
- Promote innovation by reflecting the latest advancements in technology and industry practices by continually updating and refining proposed benchmarks.
- Enhancing competitiveness by ensuring that the developed benchmarks remain relevant and effective in enhancing operational performance and competitiveness within the smart manufacturing sector.

2.2 General process of the contest

The competition will be held annually, with each edition focusing on a new theme that addresses a specific real-world industrial case. The themes will be selected based on their relevance to the interests of the SOHOMA community and their potential to benefit from the application of intelligent manufacturing technologies.

The contestants will have the opportunity to compete in various categories, depending on the choices made by the jury at the beginning of each year. Indeed, different categories might be open for contest, either related to the problem itself (for example, online category vs. offline category, mean tardiness objective vs. makespan objective...) or to the contestant (for example, young researcher awards, international cooperation,...). Each category might have different outputs requested by the jury.

2.3 Phases of the contest

The competition will be conducted in several structured phases, each designed to guide participants through the process of developing and refining practical benchmarks for smart manufacturing and then testing their solutions on the problems. The phases of the contest of Year N can be outlined as follows:

1. **January to May Year N-1 - Call for new Theme**: The contest organizing committee receives and evaluates the propositions of the community related to the new theme to be used.
2. **May Year N-1 - Theme Definition**: A preliminary announcement of the theme will be made in order to have early feedback on the interest of the problem and structure a group of experts able to describe the problem definition. During the following months, based on this theme, this group will define the case study and metrics that will be announced after summer break.
3. **September Year N-1 - Theme Announcement**: At the beginning of each competition cycle (during the SOHOMA Annual conference), the theme and specific industrial case will be announced. Detailed descriptions of the problem, objectives, and evaluation criteria will be provided. Key Performance Indicators specific to the dedicated problem will be defined by the organizing committee.
4. **From September Year N-1 to May Year N - Registration and Team Formation**: Participants, including both senior and/or junior researchers as well as industry practitioners, will register for the competition. Teams can be formed within institutions or through cross-institutional collaborations. This registration will ensure that contestants receive all the updates from the organizing committee as soon as possible.
5. **from October Year N-1 to February Year N - Publication of the problem on a web platform**: The data and specific elements of the problem will be made incrementally available online (website to be announced) for the contestants. A discussion platform will also be made available for the registered contestants to discuss with the organizing committee, and a FAQ will be designed to make public the answers to the questions of the contestants.
6. **End of July/Early August Year N - Submission of the contestants' proposals**: Teams will submit their final proposed solutions and benchmarks, along with detailed documentation of their methodologies, simulation models, and results for all instances.
7. **End of August/Early September Year N - Evaluation and Validation**: A panel of experts from academia will evaluate the submissions based on criteria such as scientific rigor, practical applicability, innovation, and potential impact on the industry.
8. **During SOHOMA edition Year N - Announcement of Winners**: The top-performing teams will be recognized and awarded during the SOHOMA yearly conference.
9. **Publication and Dissemination:** The winning methodologies will be reviewed, refined, and made public together with the problem in the web platform of the

benchmark, therefore becoming available for the smart manufacturing community. Publication and dissemination through academic journals, industry conferences, will be encouraged, either by contestants themselves or through a cross-evaluation of several solutions provided by various teams of contestants.

Fig. 1 summarizes the planning of the competition.

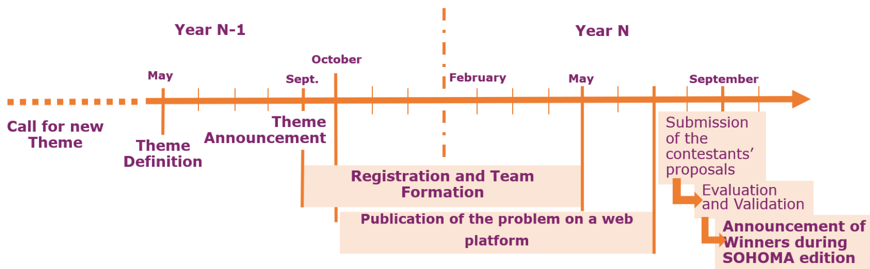

Fig. 1 Indicative Gantt chart of the competition

3 Early insights of the 2025 theme

This section introduces an early description of the 2025 contest theme, for illustrative purposes of the elements previously described. The description of the problem that will be available on the website of the contest will always be considered as the reference of the contest, even if some elements presented here are in contradiction with the website. All technical details and datasets will be provided on the website, as well as the templates for these files.

3.1 Industrial context

The problem is extracted from an industrial collaboration between the group La Poste (French postal services) and Nantes University. The purpose of this collaboration was to define suitable control strategies for an existing mail sorting system in which a 6-axis robot was going to be introduced. The overall project was called Flexibac, and a schematic representation of the expected result can be seen in Fig. 2. Pictures of the actual implementation of the robot cannot be shown due to confidentiality issues.

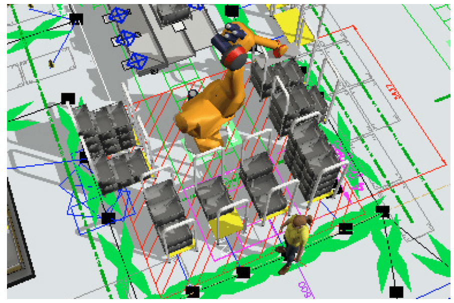

Fig. 2 Flexibac representation in Flexsim

3.2 Academic simplified representation of the model

Before the introduction of the robot, the sorting system was constituted of 250 different outputs, each corresponding to a different destination of the mail. The mail is stored in boxes, weighing approximately 20kg each, and human operators were needed to manipulate the boxes from the outputs to some carts that are later moved into trucks. Each day, the sorting system could handle between 10,000 to 35,000 boxes, which represents a high load for the workers and high risks of musculoskeletal disorders. The decision was thus made to implement a robot, aiming at manipulating as many boxes as possible.

The main problem deals with the control of the robot station. Indeed, around the robot, only 10 different carts, therefore 10 different destinations, can be positioned. However, 250 destinations can be treated each day on the system. When the system is purely manual, operators move from one cart to another freely, but the robot does not have this degree of freedom, which makes the choice of carts around the robot crucial to the global performance. These carts can be changed at any time by a human operator.

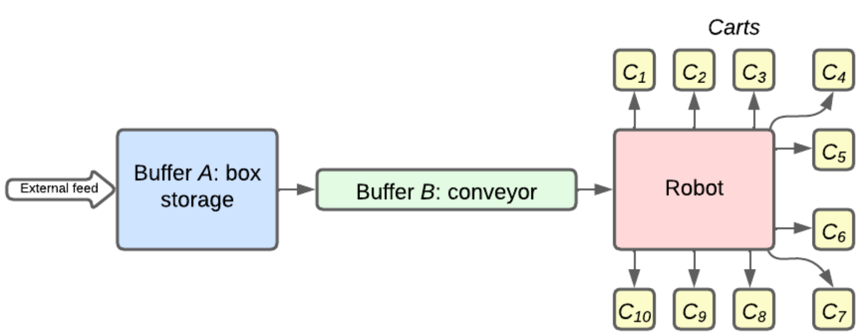

Fig. 3 Simplified system representation

3.3 Perimeter of the study

The industrial system will be voluntarily simplified here to avoid any misinterpretation. If in reality the sorting system is structured around very long conveyors (about 1 km in total), introducing travel times between different parts of the system, the considered simplified system will only be constituted of four different elements (cf. Fig 3):

- A buffer of boxes, denoted A, fed by an external element in a scheduled way, from which any box can be retrieved at any time without specific constraint, representing the loop of conveyors of the actual system. This buffer has a limited capacity denoted A_{max}. Hard constraint: the arrival of new boxes cannot be blocked by a saturation of this buffer;
- A FIFO buffer of boxes, denoted B, representing the input conveyor of the robot, with a limited capacity denoted B_{max};
- A robot, able to handle one box at a time, with a given cycle time for the pick and place operations denoted T_p;
- Carts, with a given capacity of boxes denoted Q_{max}. The time to change a cart (full or not) is fixed and denoted T_c.

3.4 Results expression and validation

3.4.1 Inputs of the problems

Each problem will be described by a set of data constituted by:

- A value of the problem parameters: $A_{max}, B_{max}, T_p, Q_{max}, T_c$;
- A list of input dates and destinations of the boxes in buffer A;
- According to the problem, some information about the distribution of destinations in the list.

3.4.2 Key performance indicators

The performance indicators that will be evaluated on this problem are twofold, with a priority given to the first one:

1. The number of boxes the robot handles in a 24h period. The priority of the problem is to provide a solution to decrease the number of boxes handled manually, hence maximizing this indicator;
2. The number of carts that were brought to the robot. Indeed, this indicator is related to the number of cart changes asked of the operators. As these changes are made manually and are physically difficult, it is asked to minimize this number.

3.4.3 Contest categories

Two categories will be open this year:

- **Online category**: the contestants are challenged to optimize the KPI without any prior knowledge of the list of input dates and destinations of boxes in buffer A. This case corresponds to the actual industrial case.
- **Offline category**: the contestants are challenged to optimize the KPI with prior knowledge of the list of input dates and destinations of boxes in buffer A. Although unrealistic in the actual industrial problem, this category is interesting for trying to reach optimal solutions to be compared with the results of the online category. Due to the nature of the problem, the time needed for calculating the solution will be requested from the contestants in the report (see below).

3.4.4 Outputs of the problem

Together with the evaluation of the KPI, the results of each resolution will also be provided in two separate files for validation purposes:

- The first file specifies the list of dates of transfer of each box from buffer A to buffer B (in ascending order of dates);
- The second file specifies the list of dates of cart changes at each position (in ascending order of dates).

The organizing committee will provide a template for each of these files and a validation model that will be freely used by the contestants and the jury for KPI validation.

Finally, the contestants will be asked to provide a written report stating, for each problem, the principle of the solution that led to these results. The template of this report will be the template offered by the 2025 edition of the SOHOMA workshop.

4 Conclusion and perspectives

This article demonstrates the complexity of constructing a benchmark, a task already difficult in itself, but made even more challenging by the need to maintain and evolve it. To address this challenge, an innovative approach is proposed: to progressively complete, year after year, a benchmark for the intelligent manufacturing community.

This approach is based on soliciting the community through an annual competition focusing on real industrial problems of complex systems management. The topic of the competition, defined annually by a call to the community and validated by a panel of scientific experts, should be broad enough to allow the application of various piloting techniques, including those from operations research, multi-agent systems, or machine learning. The next topic, focusing on postal sorting, is a promising testing ground and a stimulating challenge for both experienced researchers and master's students. We hope that this competition will attract a large number of participants and encourage massive participation in the first edition of the IMIC Challenge.

Even if this first edition is only about to start, we will soon start to design the next edition of the IMIC challenge, by sending in January 2025 the first Call for Competition Subject Proposal. The results of the first IMIC challenge, as well as the new competition theme, will then be presented in the next 2025 SOHOMA workshop.

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