Tec4MaaSEs

Technologies for Manufacturing as a Service Ecosystems

Scheduling-driven MaaS through interoperable digital twins

Prof. Ioannis Mourtos, Technical Coordinator

Athens University of Economics and Business, Greece

mourtos@aueb.gr

Asset DTs (AAS) **Matching and service composition**

RL & Optimization **Data space APIs** **Supply chain DTs**



Co-funded by the European Union under Grant No 101138517. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Health and Digital Executive Agency (HaDEA). Neither the European Union nor the granting authority can be held responsible for them.

Tec4MaaSEs
Technologies for Manufacturing as a Service Ecosystems

Manufacturing is becoming a service

Moving from dedicated, capital-heavy machinery to shared capabilities across ad hoc value networks.

TRADITIONAL MODEL

Dedicated assets

High upfront capital investment, fixed capacity lines, underutilization.

MAAS ECOSYSTEM

Shared capabilities

On-demand production capacity, offered to interested consumers. Both now benefit.

MaaS unlocks resilient value chains by pairing idle machine time with real-time industrial demand enabling all consumers to manufacture at a fraction of cost.

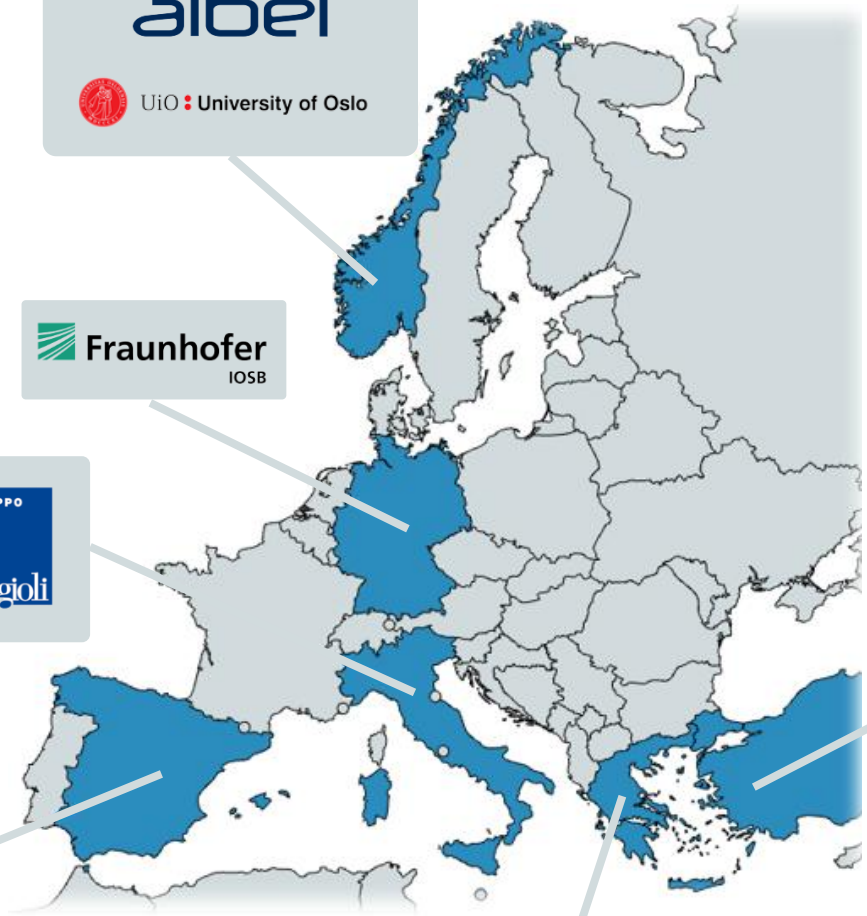


Tec4MaaSEs

Technologies for Manufacturing as a Service Ecosystems

13
partners across Europe

3
Value networks



aibel

UiO : University of Oslo

Fraunhofer IOSB

GRUPPO Maggioli

Tekniker
MEMBER OF BASQUE RESEARCH & TECHNOLOGY ALLIANCE

ERREKA

MOLDES URA
MOLDES DE INYECCIÓN

SmartOpt

Arçelik

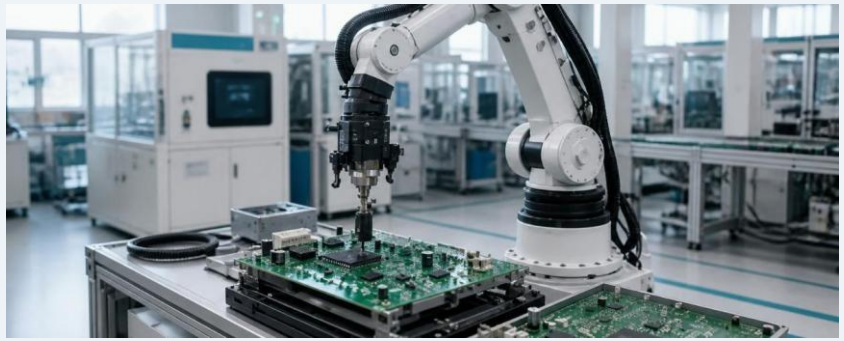
KAREL

E-BUSINESS RESEARCH CENTER
ELTRUN
ATHENS UNIVERSITY OF ECONOMICS AND BUSINESS

ATC
ATHENS TECHNOLOGY CENTER

UNIVERSITY OF MACEDONIA

3 Value networks, three real tests







VALUE NETWORK 1

Electronic boards for white goods

Enabling supply chain coordination and inter-plant allocation and balancing of batch orders through several providers

VALUE NETWORK 2

Additive manufacturing for injection moulding

The archetype of MaaS Manufacturing Services Marketplace and flexible resource sharing. 1-to-1, Many-to-1 matching through decomposition of products and automated development of value network composition

VALUE NETWORK 3

Facilities construction for the hydrogen market

Enabling collaborative engineering through IMF based semantic data exchange between engineering contractors and certified equipment suppliers.

VN1 · MAAS FOR SUPPLY CHAIN COORDINATION

Electronic boards for white goods

Synchronizing high-volume surface-mount production across distributed European factories.

Inter-plant balancing

Dynamic reallocation, reroutes batch orders when plant backlogs or component shortages arise across different suppliers.

Optimal demand forecasting

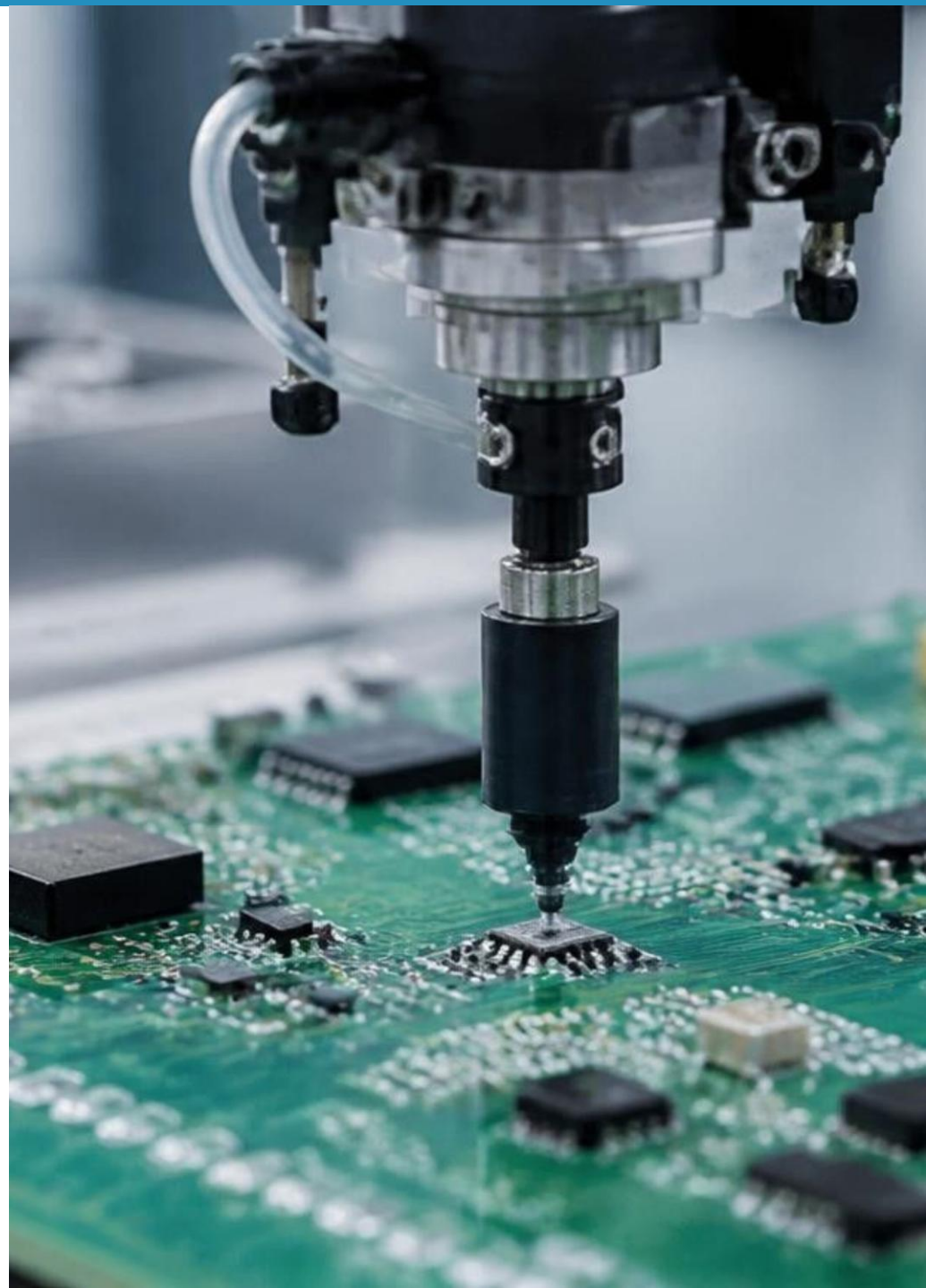
Guarantee lot-level prediction of future orders for electronic boards embedded in appliances.

Production Capacity Utilization Rate

Order Fulfilment Rate

Electronic Board Stock

Arçelik KAREL SmartOpt





VN2 · MAAS FOR MANUFACTURING SERVICES MARKETPLACE

Dynamic Manufacturing Services Marketplace for Additive Manufacturing, Machining and Plastic Injection Moulding

Enabling flexible capacity sharing, on-demand orchestration of single providers or multi-partner supply chains, and end-to-end traceability.

Dynamic service exposure

Dynamic service exposure of capabilities and capacity through AAS Digital Twins and trusted Data Spaces.

Smart product decomposition

Analysis of 3D models to extract requirements and generate a Bill of Processes for service decomposition.

Optimised value chains

Matching and optimisation of capabilities and capacity to compose single-provider or multi-partner value chains.

Negotiation and follow-up

Integrated negotiation and follow-up to trace agreements, orders and performance throughout the service lifecycle.

Product Lead Time	Machine Capacity Utilization Rate	Reduction in Investment Costs	Investment Costs in Stored Parts

ERREKA

MOLDES URA
MOLDES DE INYECCIÓN

Tekniker
MEMBER OF BASQUE RESEARCH & TECHNOLOGY ALLIANCE

VN3 · MAAS FOR COLLABORATIVE ENGINEERING

Facilities construction for the hydrogen market

Handling provider – consumer interactions with engineering complexity in hydrogen facilities' construction projects.

Syntactic and semantic interoperability

An Information Modeling Framework enabling EPC contractors and equipment vendors share specs without translation loss, speeding data interchange.

Documents Import Time	Submission – Issuance Timespan	Automated Import / Exports	Verification Effort Reduced

aibel

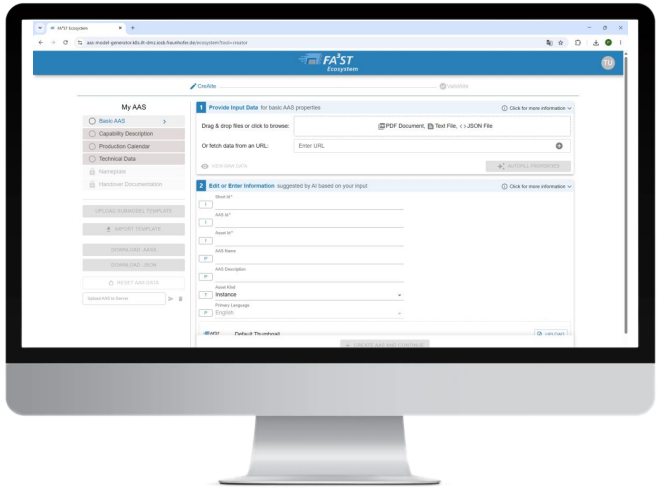
UiO : University of Oslo

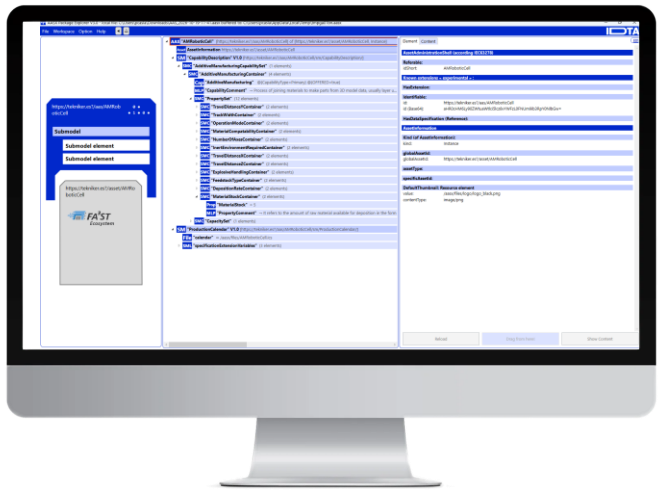


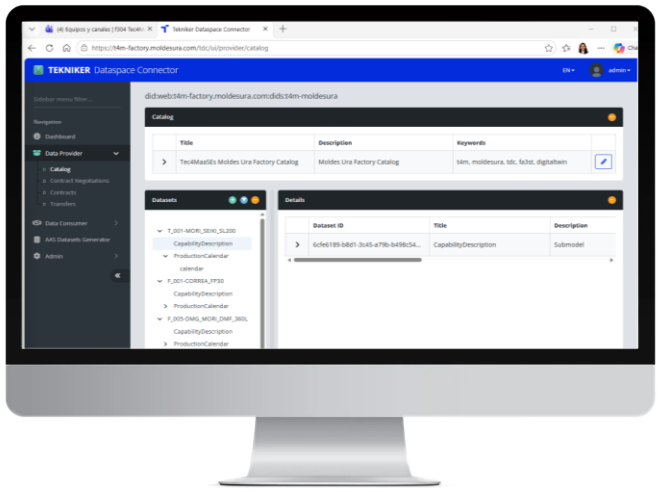
Tec4MaaSEs

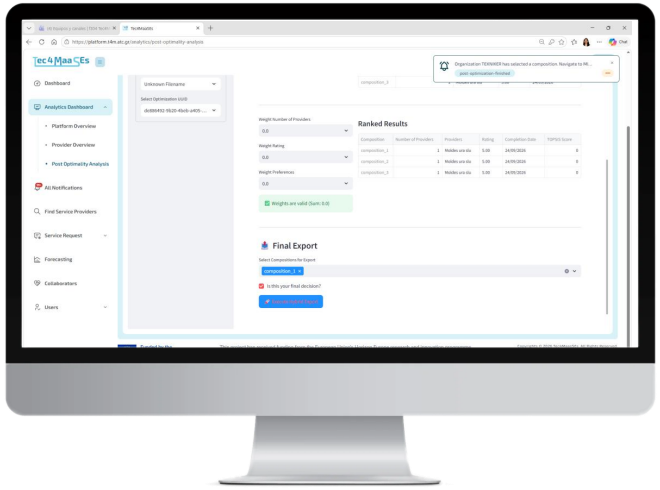
Technologies for Manufacturing as a Service Ecosystems

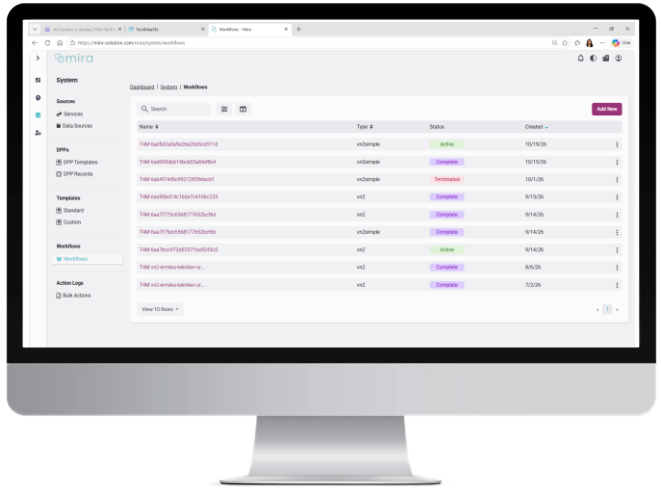
One platform to connect Providers' spare capacity with Consumers' needs

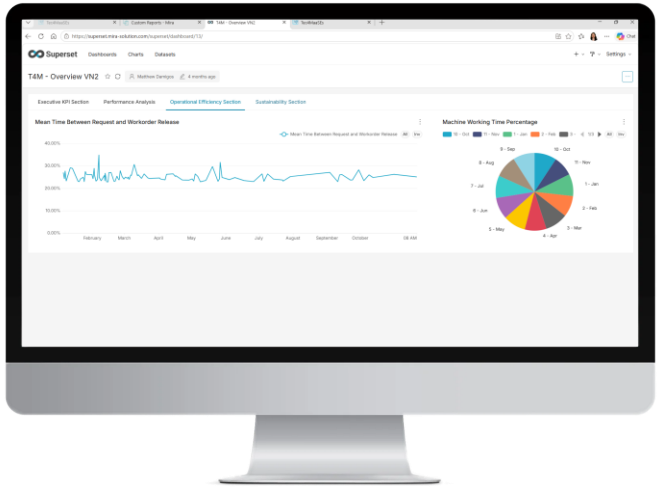












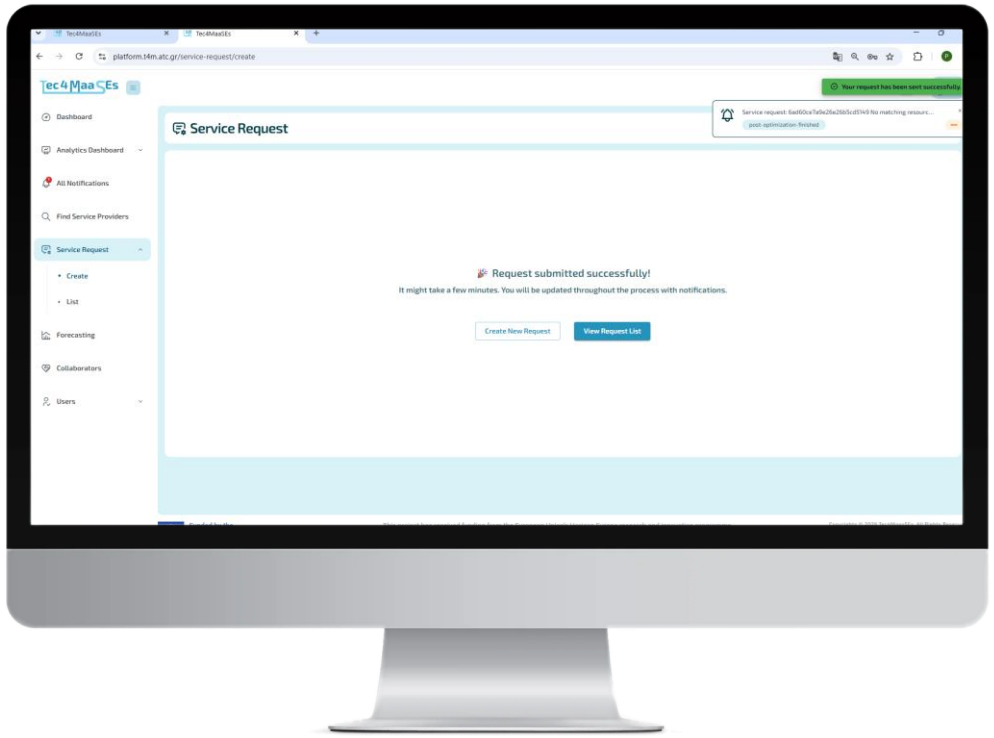
Tec4MaaSEs
Technologies for Manufacturing as a Service Ecosystems

Innovation highlights

MaaS-Specific Reference models

Information Modelling Framework

Negotiation and Ad hoc value network formation



AAS-based Digital Twins

Data Space Connectors

Forecasting

Analytics

Optimization

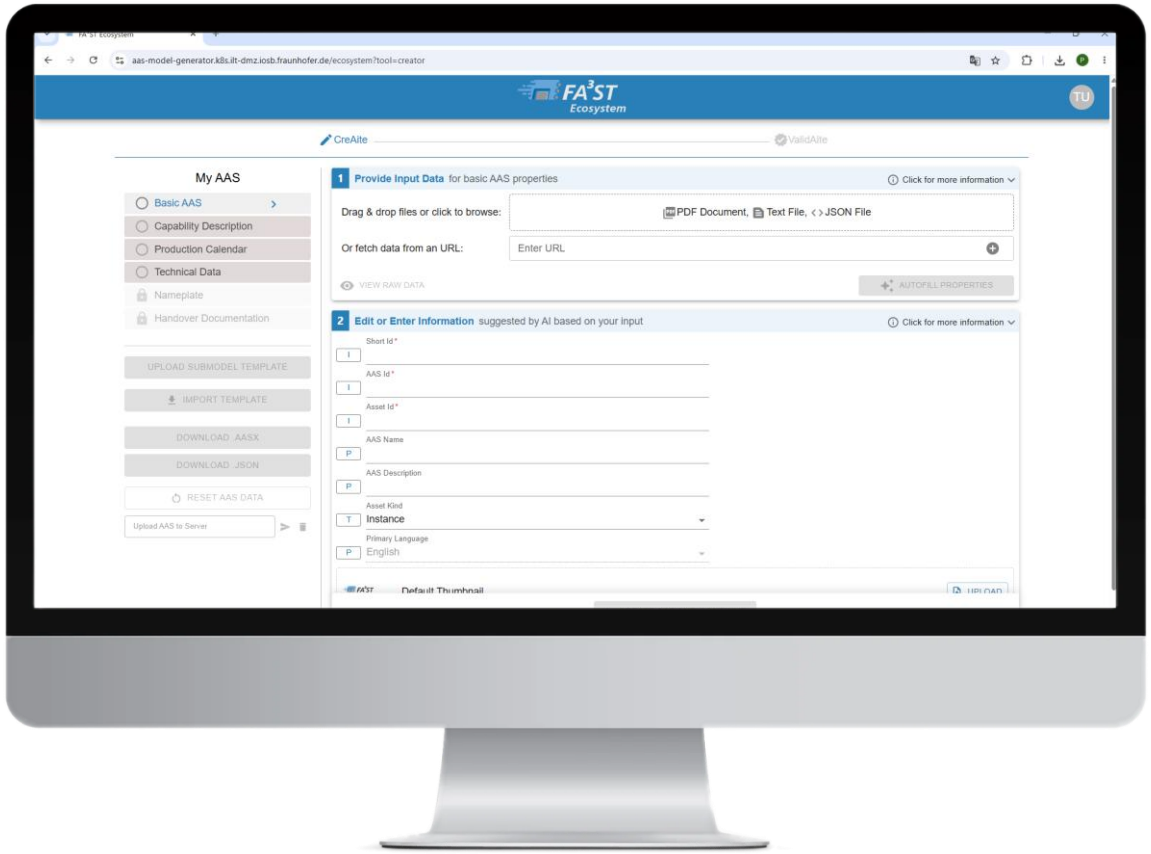
Bill of Process Generator

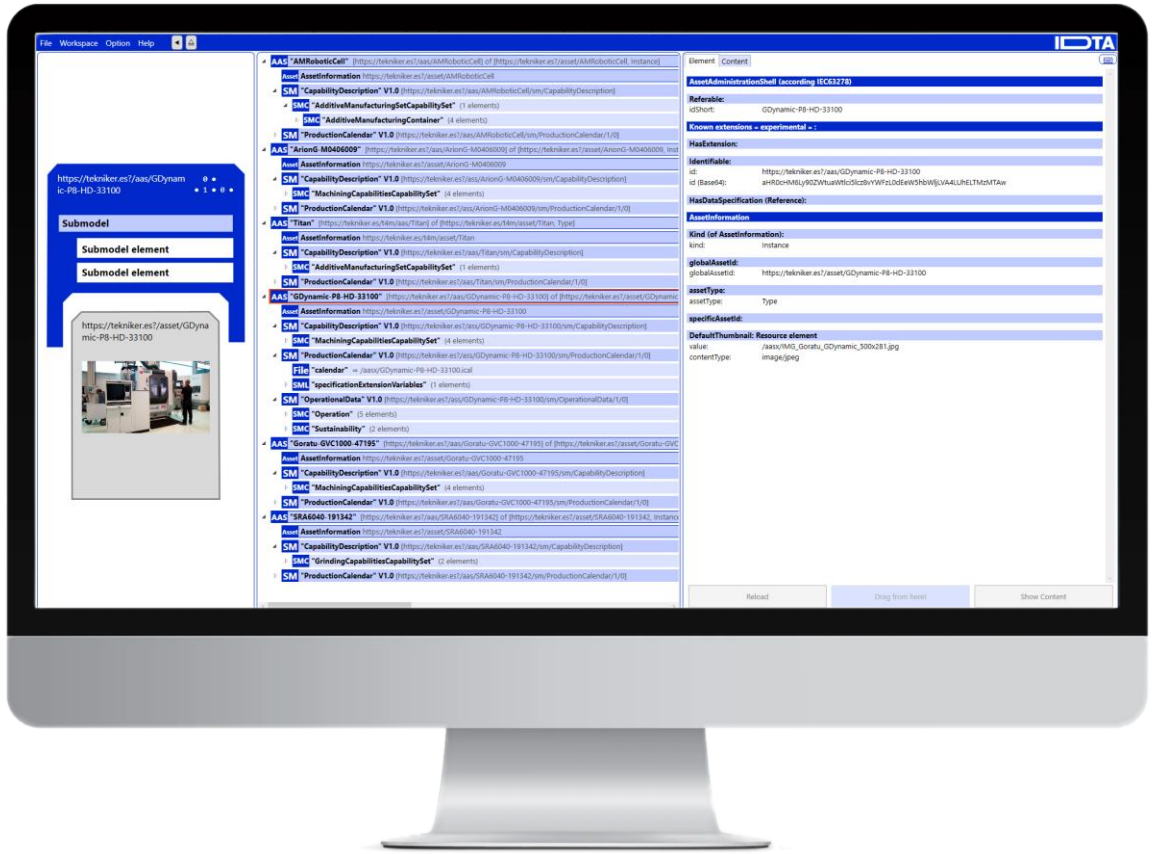
Balanced Scorecard

AI Passport

Tec4MaaSEs
Technologies for Manufacturing as a Service Ecosystems

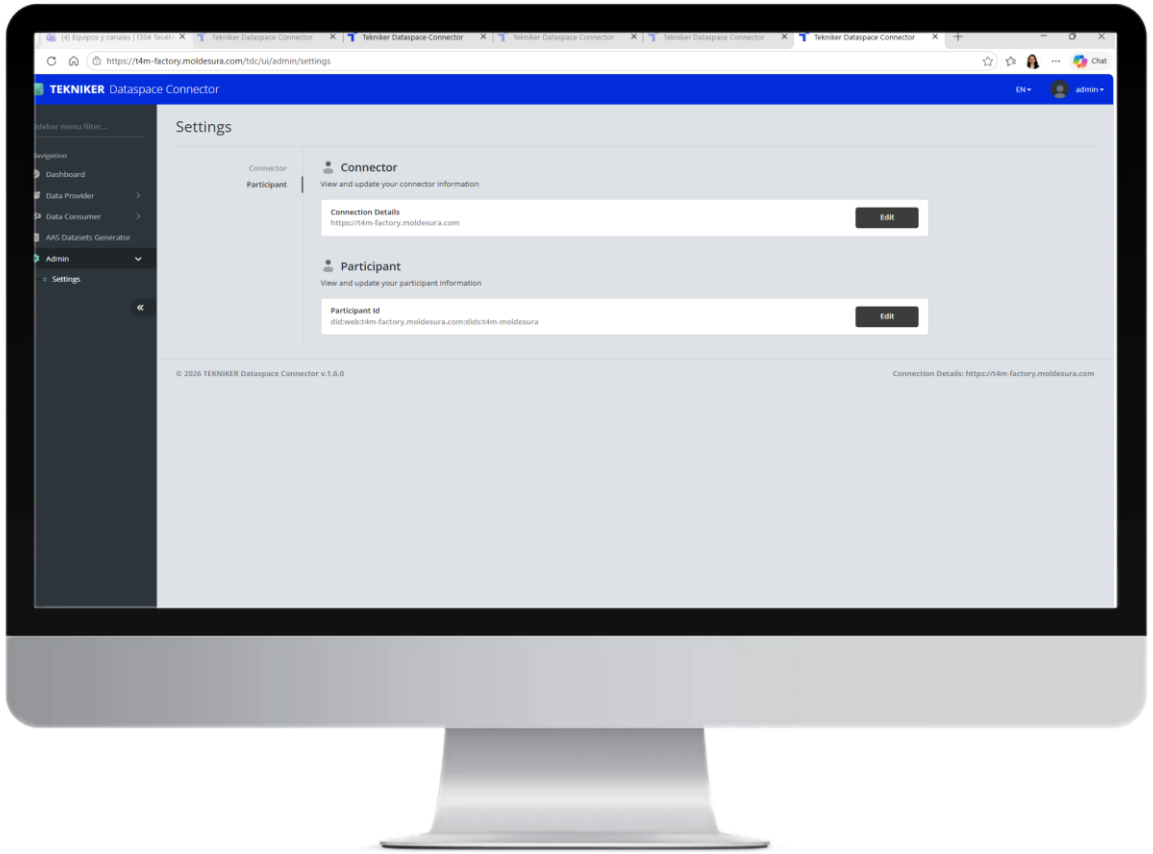
A simple process (Provider)

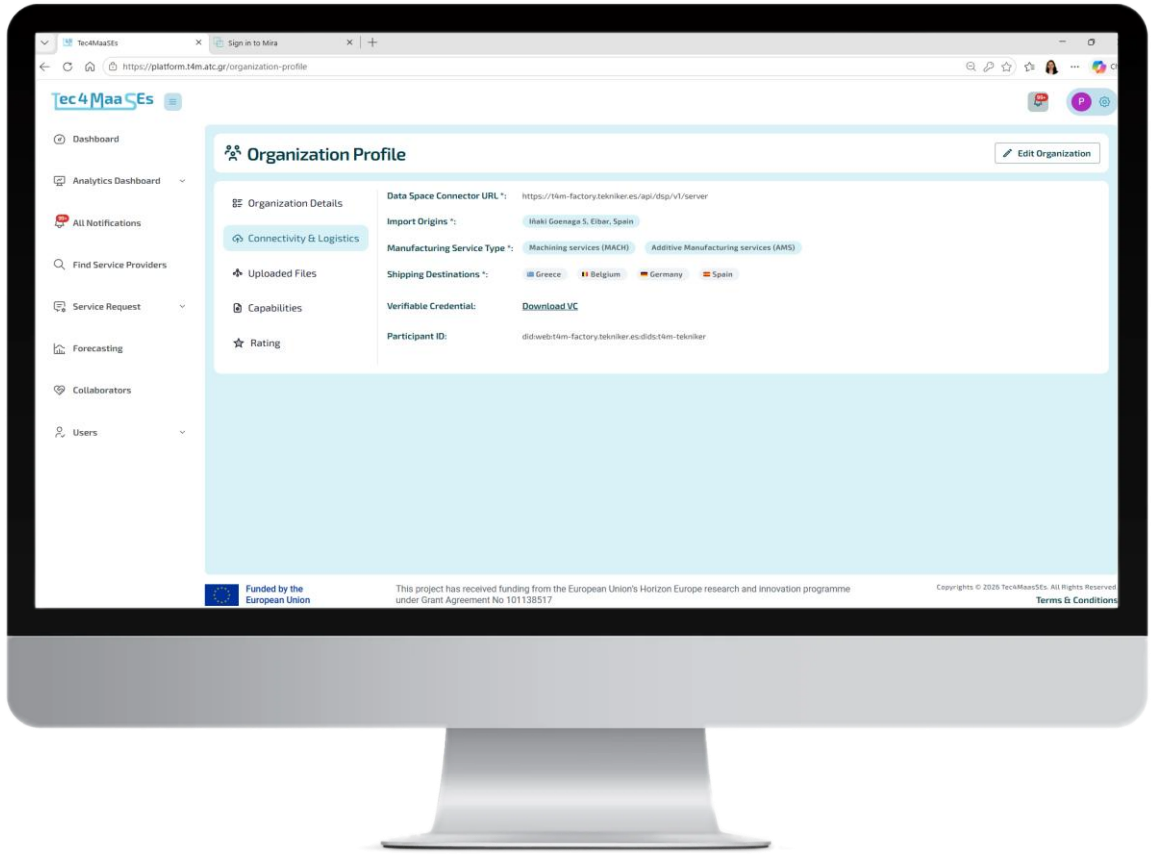




Generate and Validate
Manufacturing Resources AAS Models

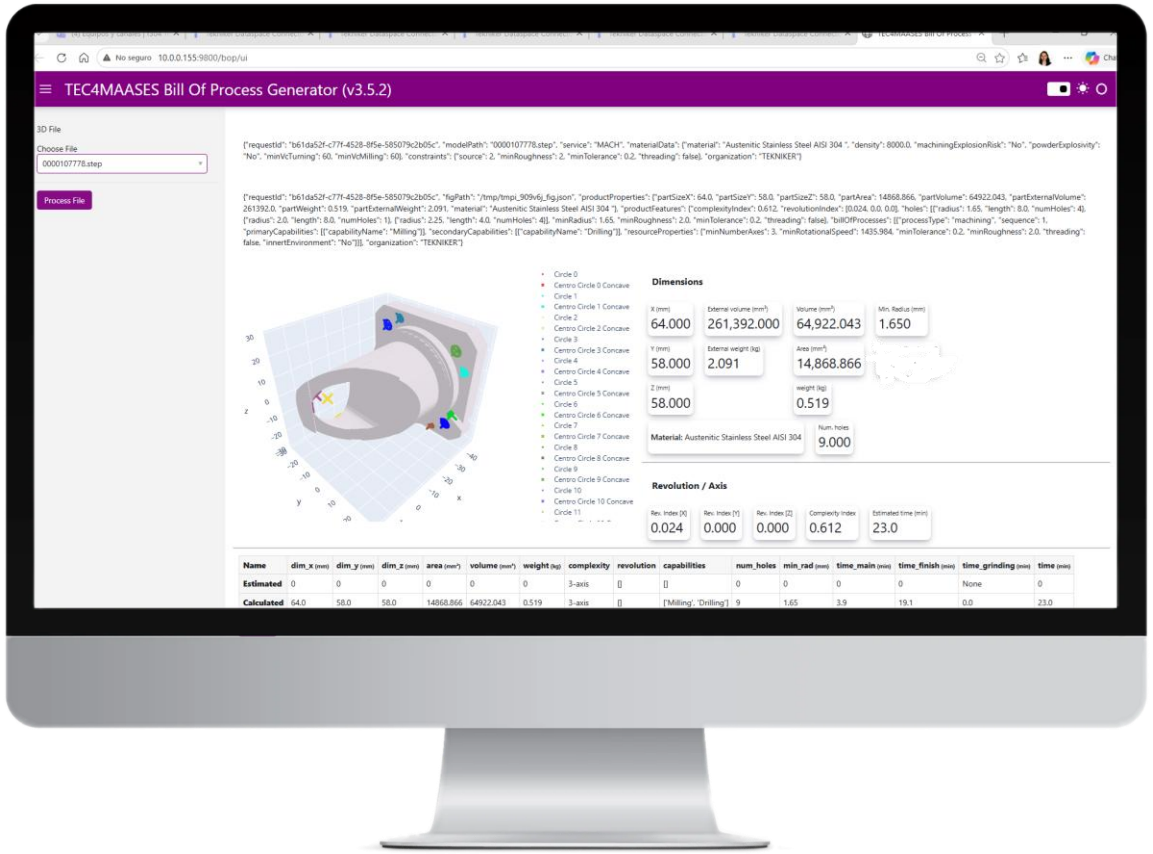
A simple process (Provider)

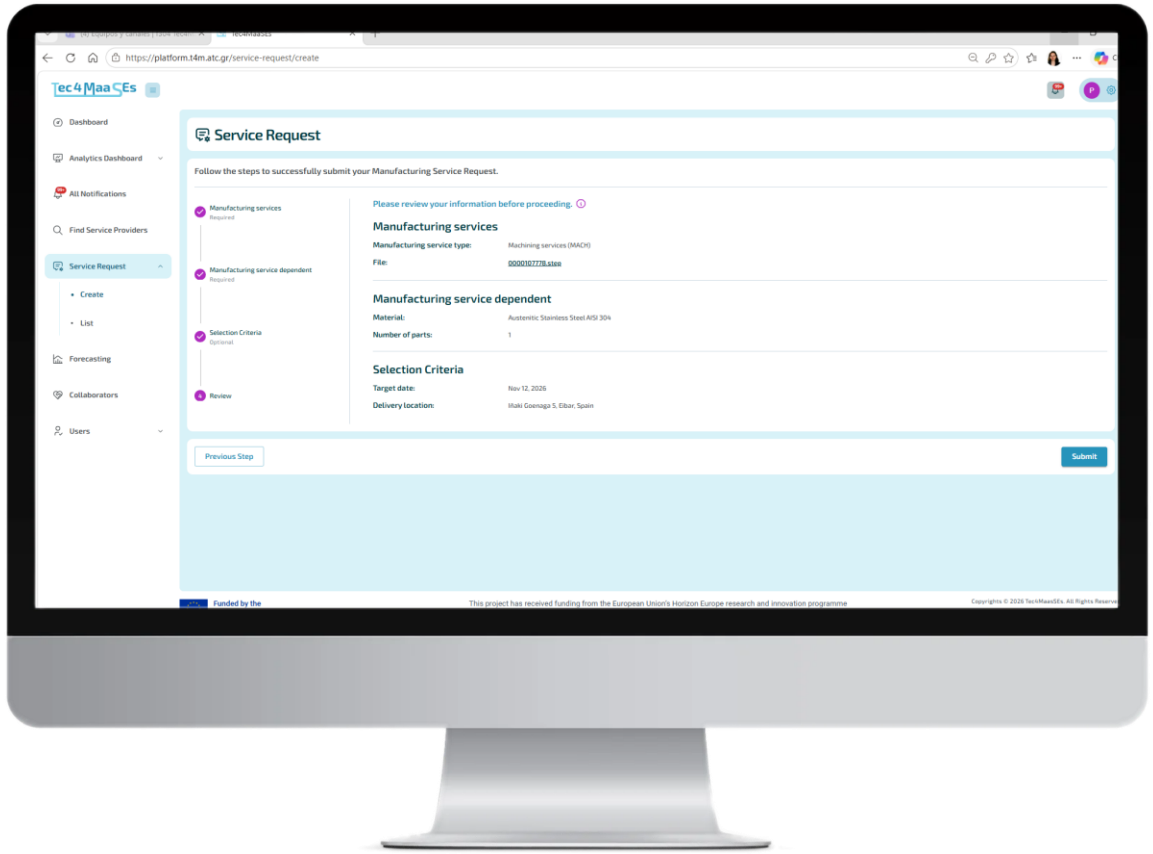




Connect and Utilize them

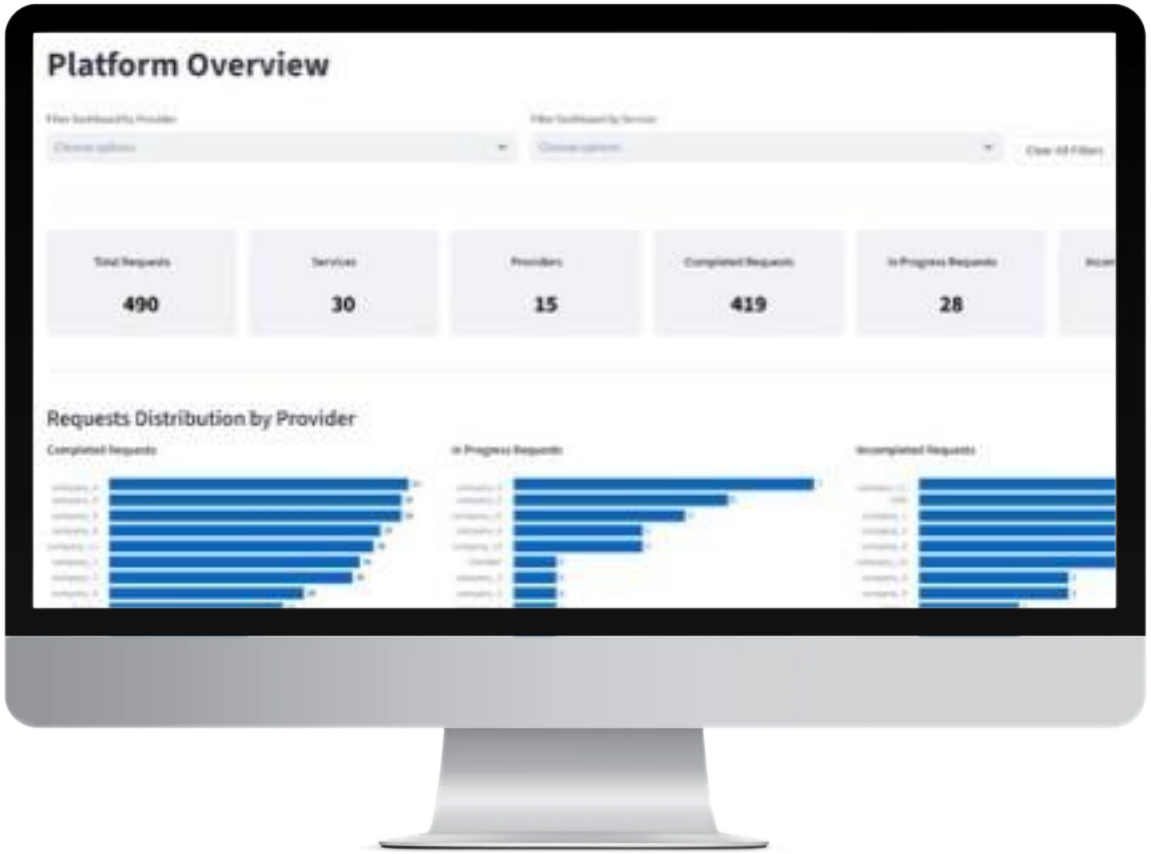
A simple process (Consumer)

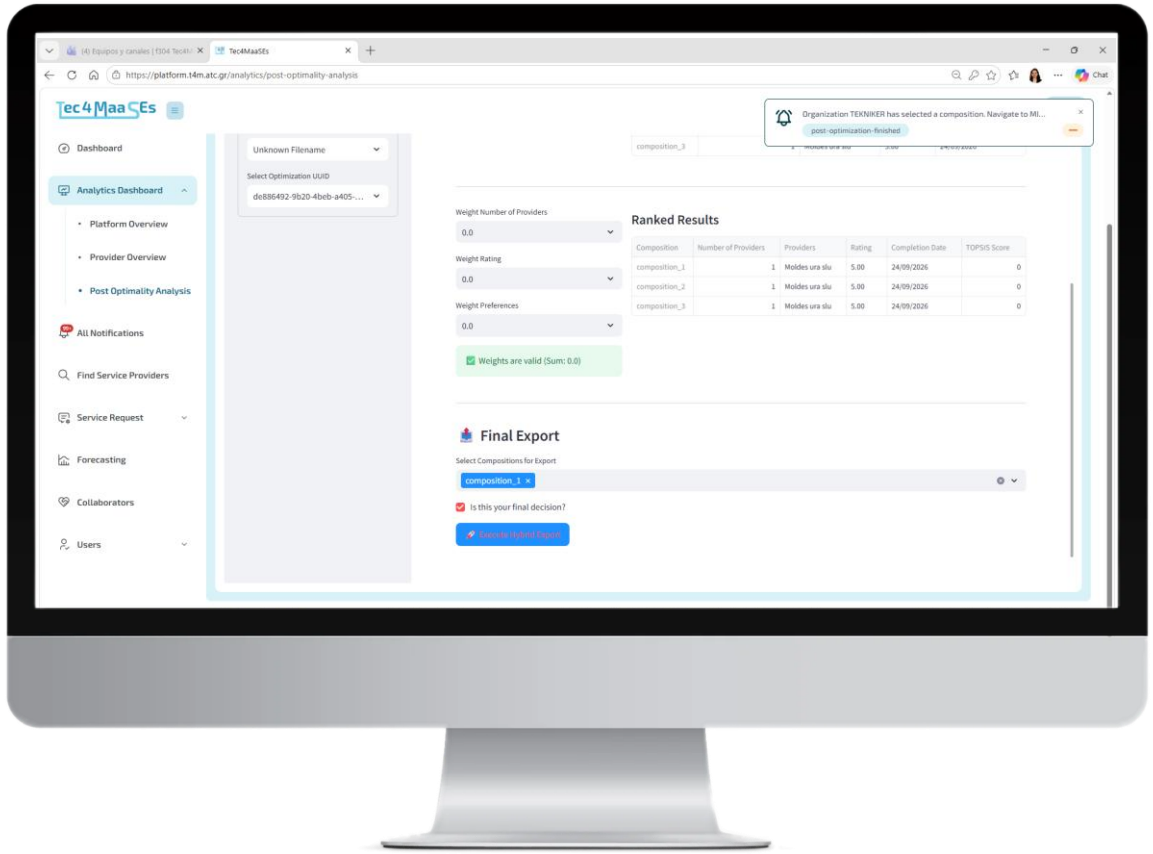




A product is decomposed and a search for a network of providers able to produce it, is initiated.

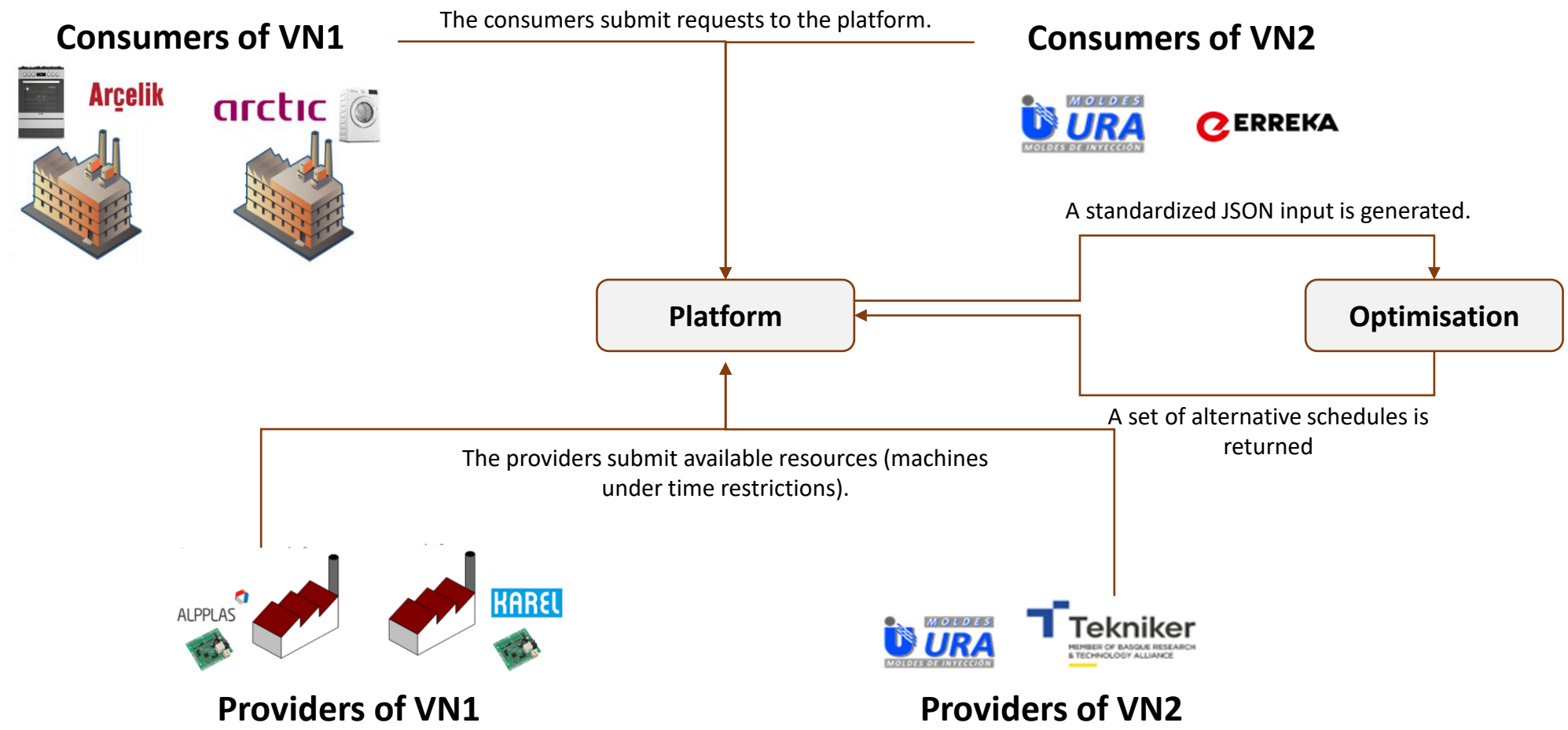
A simple process (Consumer)





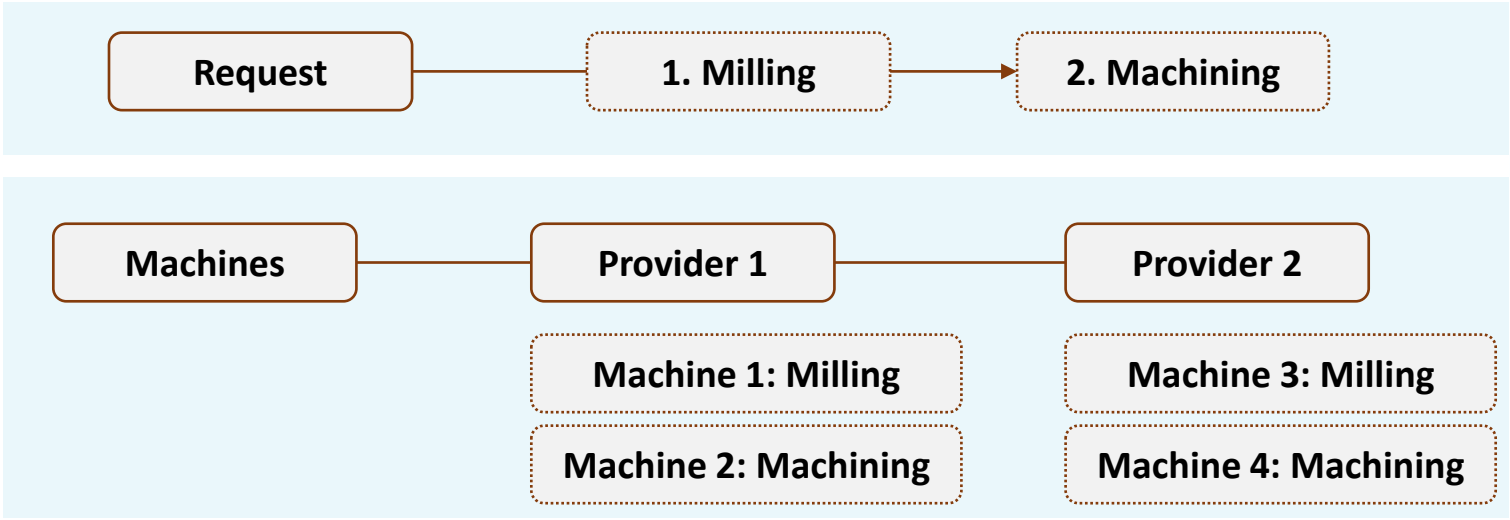
Optimal Value Networks are identified and the Consumer can make an informed decision on which to utilize for their production.

Overview of the process flow

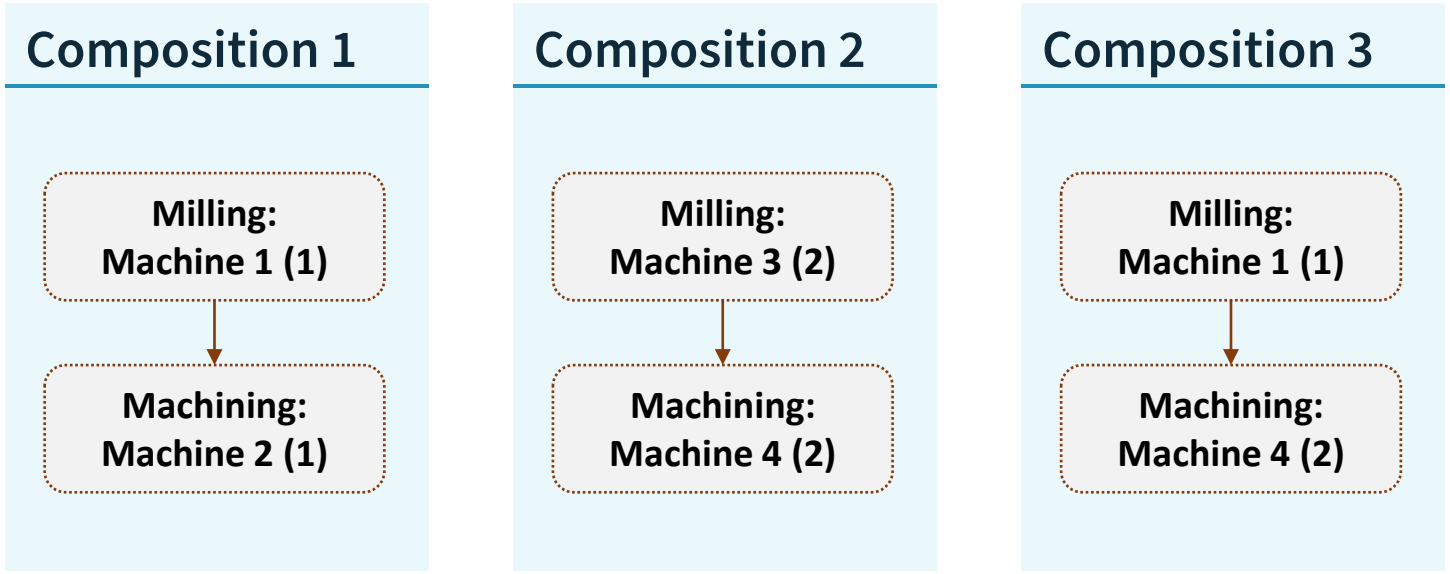


A minimal example

Input



Output



Flexibility in MaaS environments

Distributed Flexible Job Shop Scheduling:

- **Distributed:** Each request must be entirely processed by a single manufacturing unit (industrial provider)
- **Flexible:** Parallel machines can eligibly process the same operation.
- **Job Shop:** Each request includes multiple operations to be conducted in predefined sequence

For VN1:

- Each request must be assigned to one provider (**distributed**)
- Each provider has multiple parallel production lines (**flexible**)
- Each request has a sequence of stages (reduced to **flow shop**)

For VN2:

- Operations of the same request can be processed by different providers (relaxation of the **distributed** aspect)
- Each provider has multiple parallel machines (**flexible**)
- Each request has a sequence of operations (**job shop**)

Flexibility in MaaS environments

Constraint Programming models can address these formulations to solve instances of **thousands of operations**:

Objectives:
- **VN1:** Minimisation of earliness and tardiness (Just-in-Time scheduling)
- **VN2:** Minimisation of makespan and maximization of locality (i.e., preference for local providers)

Common objective: Load imbalance – the participating providers should receive a fair allocation of requests

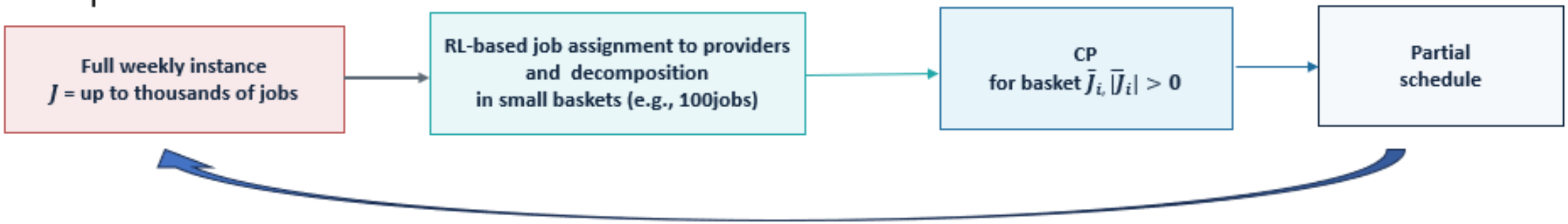
The role of optimisation:
- Introduction of critical KPIs as objectives to be minimised/maximised.
- Feasibility guarantees: CP models ensure that the generated schedules satisfy all industrial restrictions.
- Flexibility: Models for state-of-the-art scheduling problems can be easily modified to address tailored solutions.

Complementarity with analytics:
- Analytics complements optimization by providing data-driven insights for performance assessment and decision support across MaaS value networks.

Scalability

Demand requests may include thousands of products to be scheduled:

- Current practices: heuristics to group products with similar aspects, and reduce the scale of the problem to be solved
- Innovation: Reinforcement Learning mechanisms to decompose the problem into sequential subproblems.



RL learns high-level orchestration

- which jobs should be added in a basket at each state
- which provider should process each job
- how early assignments affect later baskets

A Reduced CP

- basket $\bar{J}_i$ is fixed with providers already assigned
- machine release times inherit previous baskets
- at each iteration CP solves a basket and updates the partial schedule

RL does not replace CP — it steers CP toward scalable, high-quality solutions

Tec4MaaSEs
Technologies for Manufacturing as a Service Ecosystems

Scalability

Solutions for instances of thousands of operations in seconds:

Instance	Objective values		Time
	total E/T (minutes)($\times 10^6$)	LI^{norm}	
500_1	0.003	0.00	86
500_2	0.003	0.00	87
500_3	0.003	0.00	86
800_1	0.004	0.01	139
800_2	0.004	0.01	139
800_3	0.004	0.01	136
1000_1	1.038	0.02	170
1000_2	0.005	0.01	173
1000_3	0.005	0.01	170
2000_1	0.010	0.02	341
2000_2	0.010	0.02	340
2000_3	0.010	0.02	342
5000_1	0.304	0.05	865
5000_2	0.304	0.05	863
5000_3	0.226	0.06	870
10000_1	0.536	0.05	1777
10000_2	0.536	0.05	1781
10000_3	0.536	0.05	1781

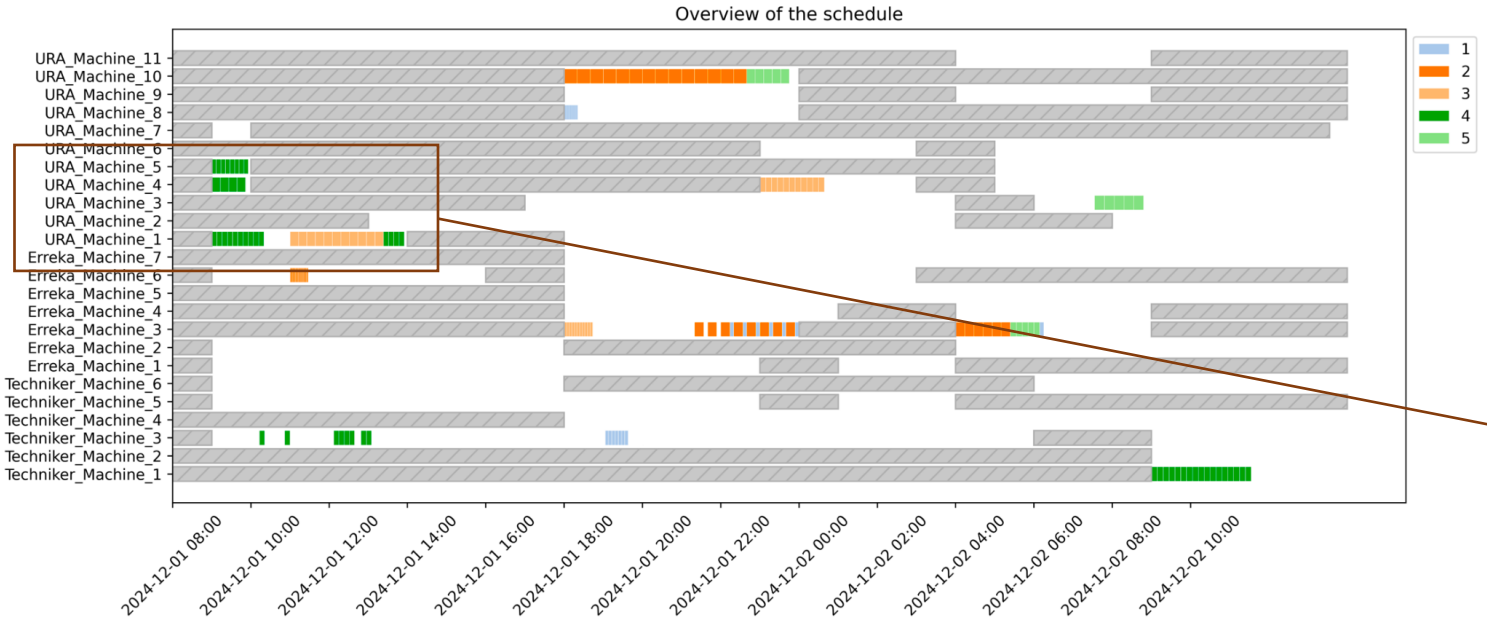
Comparison with baseline values of standard methods:

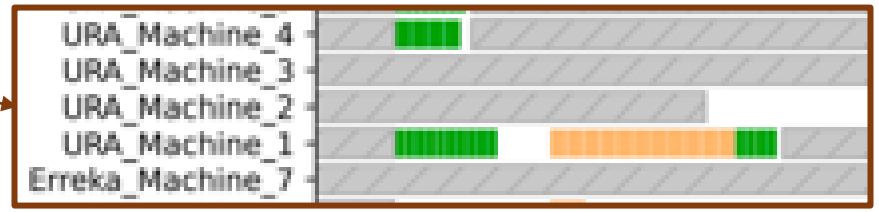
CP model				Standalone metaheuristic		
total E/T (minutes)($\times 10^6$)			LI^{norm}	total E/T ($\times 10^6$)	LI^{norm}	Time
1,200	2,400	3,600				
0.362	0.273	0.087	0.14	1.154	0.08	206
0.361	0.284	0.090	0.02	1.126	0.19	204
0.952	0.318	0.255	0.25	1.070	0.09	205
-	1.559	0.267	0.30	1.716	0.08	223
0.858	0.223	0.222	0.08	1.662	0.25	220
1.513	0.465	0.465	0.96	1.482	0.11	225
-	1.816	1.546	0.42	1.996	0.08	236
1.896	1.317	0.420	0.10	1.938	0.24	232
1.798	1.798	1.798	0.88	1.685	0.13	240
3.479	3.479	3.479	0.52	3.161	0.05	240
3.645	3.645	3.399	0.40	1.989	0.43	240
3.382	3.382	3.382	0.91	2.006	0.09	240
-	-	-	-	1.343	0.02	240
-	-	-	-	2.556	0.04	240
-	-	-	-	2.246	0.05	240
-	-	-	-	17.804	0.03	427
-	-	-	-	14.960	0.00	240
-	-	-	-	29.972	0.00	387

total E/T: Total earliness and tardiness
LI: Load Imbalance (fairness metric)

Time restrictions

Time windows usually appear in a discontinuous manner:





Addressing these restrictions allows for dynamic scheduling over a rolling horizon: previous assignments appear as time intervals of unavailability in future optimisation runs.

Exploitation of enclaved time intervals of machine availability contribute to more efficient production schedules.

Indicative papers

- Kaparis, K., Georgiou, A. C., Lounis, S., Turkay, M., & Ozcan, M. C. (2025). Designing a manufacturing as a service ecosystem through distributed value networks and structured volume-variety dynamics. **International Journal of Systems Science: Operations & Logistics**, 12(1), Article 2597349. https://doi.org/10.1080/23302674.2025.2597349

- Avgerinos, I., Mourtos, I., Papathanasiou, D., & Zois, G. (2026). Resource-dependent process times in hybrid flexible flowshops: A Constraint Programming-oriented decomposition approach. **European Journal of Operational Research**. https://doi.org/10.1016/j.ejor.2026.07.015

- Skjæveland, M. G., & Karlsen, L. H. (2024). The Reasonable Ontology Templates Framework. **Transactions on Graph Data and Knowledge**, 2(2), 5:1–5:54. https://doi.org/10.4230/TGDK.2.2.5

- Lyu, Q., Skjæveland, M. G., Li, S., Rao, Y., Soylu, A., Kiritsis, D., Waaler, A., & Zhou, B. (2026). Generating explainable and verified product information models from industrial documentation. **Journal of Computing and Information Science in Engineering**, 26(8), Article 081004. https://doi.org/10.1115/1.4071963

Tec4MaaSEs

Technologies for Manufacturing as a Service Ecosystems

Thank you

JOIN THE PROJECT

Follow Tec4MaaSEs

www.tec4maases.eu

info@tec4maases.eu

Prof. Ioannis Mourtos

Athens University of Economics and Business, Greece, mourtos@aueb.gr

@tec4maases