Information Modeling Using Asset Administration Shell for Legacy Manufacturing Systems

Vitor Mendes Caldana
Federal Institute of Sao Paulo (IFSP) – Sorocaba Campus
Sorocaba, Sao Paulo, Brazil
vitor.caldana@ifsp.edu.br

João Paulo Pinheiro Barbosa & Eduardo Paciencia Godoy
São Paulo State University (UNESP) – Sorocaba Campus
Sorocaba, Sao Paulo, Brazil
jpp.barbosa@unesp.br ; eduardo.godoy@unesp.br

Abstract

The advent of Industry 4.0 has introduced significant advantages in information and communication technologies but also presents challenges, such as the need for standardization to ensure interoperability, especially in legacy systems. This paper explores information modeling using the Asset Administration Shell (AAS), applied to a Flexible Manufacturing System (FMS) from Festo. The aim is to demonstrate how AAS-based data modeling can structure communication between machines and systems on Legacy Systems. AAS submodels were created using the Eclipse AASX Package Explorer. In addition to modeling, a proof of concept was achieved by integrating AAS into an OPC UA server via Node-RED. The results show the potential of AAS but highlight challenges such as adapting legacy systems and implementing current technologies.

Keywords
Industry 4.0, AAS, FMS, Legacy Systems, OPC UA

1. Introduction
The rapid evolution of technology, particularly in the manufacturing industry, has led to the emergence of Industry 4.0, a new paradigm that integrates physical processes with digital technologies, enabling highly automated and interconnected production environments. This concept is centered on Cyber-Physical Systems (CPS), which merge the physical and virtual worlds through the use of the Internet of Things (IoT), Big Data, and advanced communication technologies (Schwab, 2019). While Industry 4.0 offers numerous benefits, such as increased efficiency, flexibility, and the potential for mass customization, it also presents significant challenges, particularly when dealing with legacy systems that were not originally designed to integrate with these new technologies (Kutscher et al., 2020; Xavier et al., 2023). A critical issue within Industry 4.0 is the lack of a standardized model for data exchange. While there is an abundance of information generated by machines, sensors, and systems, this data is often fragmented and lacks the consistency required for seamless interoperability between different systems and platforms.(Bitsch et al., 2023)

The absence of a unified framework means that data, though abundant, cannot always be easily shared or interpreted across diverse technologies. This lack of standardization complicates the integration of legacy systems, which traditionally rely on proprietary protocols that are not easily adaptable to the modern standards required for Industry 4.0 environments. As a result, manufacturers face significant challenges in achieving true interoperability, where all systems within a factory can communicate efficiently and effectively with one another. The challenge is not only technical but also economic, as many companies are reluctant to replace existing systems due to the high costs involved. This highlights the need for a solution that can bridge the gap between legacy and modern systems while minimizing the financial burden of upgrading entire infrastructures (Bajic et al., 2021; Rikalovic et al., 2022).

To solve the issue of interoperability several initiatives were implemented to achieve a standard for CPSs, with the purpose of integrating diverse programing languages and supplier protocols. The Reference Architectural Model Industry 4.0 - RAMI 4.0 - (ZVEI, 2015) standardized most of the features, as it is based on Open Platform

Communications – Unified Architecture (OPC UA) (Mahnke et al., 2009) for communication as well as the Asset Administration Shell – AAS - (ZVEI, 2016) as its information model. AAS provides a standardized digital representation of physical assets, allowing for seamless communication between legacy machinery and modern digital systems. AAS is being used in several industry solutions to solve the interoperability problem, however it is still on its developing stages and the final specification is not published (Quadrini et al., 2023).

With that in mind, this paper proposes a deeper study into AAS to verify the feasibility of implementation of the AAS information model to support the integration of legacy systems into the Industry 4.0 environment. This paper focuses on the implementation of AAS in a legacy Flexible Manufacturing System (FMS) using Siemens S7-300 PLCs. This is a continuation of previous works that created a OPC UA/Node-RED platform (Sousa et al., 2024) and aims to develop a solution that will implement a state-of-the-art information model that will allow legacy systems to communicate with Industry 4.0.

1.1. Objectives

The main objective of this research is to model an Asset Administration Shell (AAS) for the Flexible Manufacturing System (FMS) from Festo, which is controlled by Siemens S7-300 PLCs and displayed below in Figure 1. This AAS model aims to provide a structured digital representation of the station, allowing for seamless communication between the legacy system and modern Industry 4.0 technologies. By modeling the AAS specifically for the FMS, the project seeks to demonstrate the feasibility of implementing an information layer that can be used to upgrade legacy systems without the need for extensive hardware replacement. The study builds upon previous work and focuses on scalability, optimization, and integration.

Figure 1: FESTO FMS Legacy System

The following specific objectives are intended:

- Develop and implement an AAS model tailored to the FMS station, focusing on structuring the information model, while ensuring interoperability.
- Adapt the existing Node-RED and OPC UA environment, which utilizes legacy PLCs, to support the use of the newly developed AAS, enabling communication between the legacy system and modern protocols.
- Implement and test the AAS in a real environment, validating its functionality and evaluating its potential for real-world application in legacy systems.

The structure of the paper is as follows: on section 2 we provide the necessary literature review for AAS. On section 3 we address the creation of the AAS model. Section 4 shows the results and discuss the work performed. Section 5 is the conclusion and future work.

2. Literature Review – Asset Administration Shell

To follow is the necessary literature review to achieve the objectives described in section 1.1. As this is a continuation of previous research this review will focus on the part developed for this paper alone – the Asset Administration Shell or AAS. For more information about the infrastructure of the FMS, the PLC, Node-RED and OPC UA please refer to Sousa & Caldana (2023) and Sousa et al., (2024).

AAS is an initiative of the German platform "Industrie 4.0", the same platform that develop the term Industry 4.0, with the objective of describing "Assets" in a standardized digital form allowing interoperability between diverse systems on the factory floor. AAS is basically a digital representation of a real Asset as seen in Figure 2 with multiple submodels each representing a specific aspect of the physical asset, such as Documentation, Name Plate, Techincal Data, Operational Data and etc. AAS supports industrial automation systems, industrial assets and CPS within the product lifecycle in an environment to facilitate Digital Twin implementation, the main objective of which this research is part of. (Inigo et al., 2020; Quadrini et al., 2023)

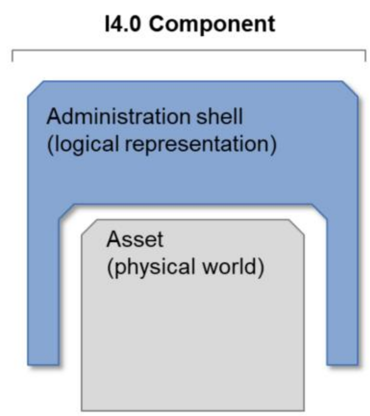

Figure 2: AAS Representation (Barnstedt et al., 2018)

AAS is divided into three different types: Type 1 – known as passive AAS; Type 2 – known as reactive AAS and Type 3 – known as proactive AAS. Type 1 is normally associated with information and sub-models that normally do not change over time, such as make, model, S/N and similar. Type 2 is associated with on-line and changeable information, such as sensors and machine and order status, in which access to the on-line servers and registry is provided through API´s. Both Type 1 and Type 2 have been stablished by Industrial Digital Twin Association (IDTA) and are currently in use. (Stolze et al., 2024). For the purposes on this paper we will focus on Types 1 and 2. Type 1 will be developed for relevant fixed information and Type 2 will be responsible for creating the necessary signals for the sensor and actuators for the stations as well as the simulated data for further integration with the Digital Twin.

AAS is composed of a header and an information field, where the header contains the necessary information to identify the asset inside AAS and the information field is comprised of several sub-models that describe specific features of such asset. As seen on Figure 4 there are several possible sub-models, with more models being developed each day as AAS is still on the development stages. The information held can be accessed by both real-world and digital-world applications, making the AAS a powerful toll for the implementation of DT. (Marcon et al., 2018)

2.1 AAS Submodels

Submodels in AAS perform an essential role in the structuring and organizing of information from the industrial asset. Each submodel acts as a container for specific data, allowing different aspects of the asset to be described in a standardized and accessible manner. This organization enables interoperability and systems integration, promoting a unified vision of the assets during their life cycle and quick access to relevant information by the API´s. Submodels are highly flexible and can be customized to meet different necessities, allowing custom solutions within a standard information model (Barnstedt et al., 2018).

One of the main organizations responsible for creating and maintaining AAS, the Industrial Digital Twin Association (IDTA), offers a series of standard submodels and information on their website[1]. These templates are designed to obtain specific and relevant information from different asset´s characteristics, such as make/model, relevant technical information, sensors and actuators status and so on. It serves as a starting point for companies that wishes to start implementing AAS assuring conformity with the RAMI 4.0 and AAS guidelines. By using the models companies can ensure that connectivity and interoperability are achieved (IDTA, 2025).

After researching the papers that use AAS as their information model such as (Abdel-Aty et al., 2022; Cavalieri & Salafia, 2020; Siatras et al., 2023; Tantik & Anderl, 2017) amongst others it was possible to identify the most used submodels. However the research did not present a submodel that could handle the simulated variables (present on a Digital Shadow for example) with clarity. To solve this GAP, this research will present in section 2.1.5 a proposed model for Simulated Data, very similar to the Operational Data submodel with the distinction of being able to show and store only the variable created by models from programs such as MathLAB.

2.1.1 Name Plate

This submodel is na enhancement of the former "Digital Name Plate". It standardizes and structures information according to Machine Directive UE 2006/42/EC. With this submodel it is possible to overcome the physical limitation of printed TAGs and the relevant information can be accessed globally, always in good condition – unlike old machine paper/metal TAGs – and without ambiguities. (IDTA, 2025). The main features of this submodel that will be included in this project are:

2.1.2 Technical Data

The Technical Data submodel captures detailed technical specifications and configurations of the asset. By digitizing this technical data, the AAS allows for real-time access to the asset's capabilities and constraints, ensuring that systems interacting with the AAS can make informed decisions based on the current state of the asset. For instance, if the legacy system needs to interface with newer equipment, the Technical Data submodel provides critical information on how the systems can be connected and configured without manual intervention. (IDTA, 2025)

2.1.3 Documentation

The Documentation submodel stores all relevant documentation related to the asset, such as user manuals, maintenance guides, repair records, schematics, programming and etc. By having this information digitally accessible, operators can quickly reference important documents without needing to search for physical copies. This not only improves operational efficiency but also ensures that maintenance and troubleshooting processes can be streamlined, particularly when integrating older systems into a new digital framework (IDTA, 2025)

2.1.4 Operational Data

The Operational Data submodel provides real-time data on the asset's performance, including its current status, operating conditions, and any error messages. The ability to create collections makes this submodel extremally functional and adaptable, as variables can be categorized between Actuators, Sensors, Control and etc. By integrating the Operational Data submodel into the AAS, the FMS is able to communicate its operational status to a Node-RED dashboard via OPC UA, ultimately providing real-time information in a Industry 4.0 standard that was not accessible before (IDTA, 2025)

2.1.5 Simulated Data – Proposed Model

The Simulated Data submodel will provide data derived from simulating models, such as models running on State Transition Table in MATLAB. By separating the real data from the simulated data, a Digital Twin system can start to be implemented. The use of such simulated data can be several from a Shadow Model that will make sure that the real system is doing what is was supposed to, to complex simulation models to asses bottlenecks, preventative maintenance and several other applications. This model is the cornerstone of bringing legacy systems to a newer position inside Industry 4.0

[1] https://industrialdigitaltwin.org/en/content-hub/submodels

3 Creating the AAS Model and Updating Node-RED

To create, manipulate and edit the submodels and the AAS file itself, Eclipse´s AASX Package Explorer[2] was used. It can use the existing submodels provided by IDTA and also allows the creation of specific and tailored models for the specific applications. In this section we will provide the information that was used to create the AAS Model of 2 stations of the FMS: Distribution and Testing. More information on how to create the AAS and use the IDTA submodels can be found in Barbosa (2024)

3.1 AAS Model

The main AAS model with the submodels described in sections 2.1.1 through 2.1.5 can be found in Figure 3 below. For this paper an Asset was created for the full FMS system. This Asset will have all major system specifications and documentation that are common to all stations. After that two new Assets were created, one for each of the station of the first production process: feeding (Distribution Station) and sorting parts (Testing Station). The Testing station only had "Operational Data" submodel created as it was vital towards the operation of the line while the Distribution Station has all five submodels mentioned above to showcase all that can be added inside the AAS structure. The FMS itself also had the documentation submodel created to insert the relevant software files.

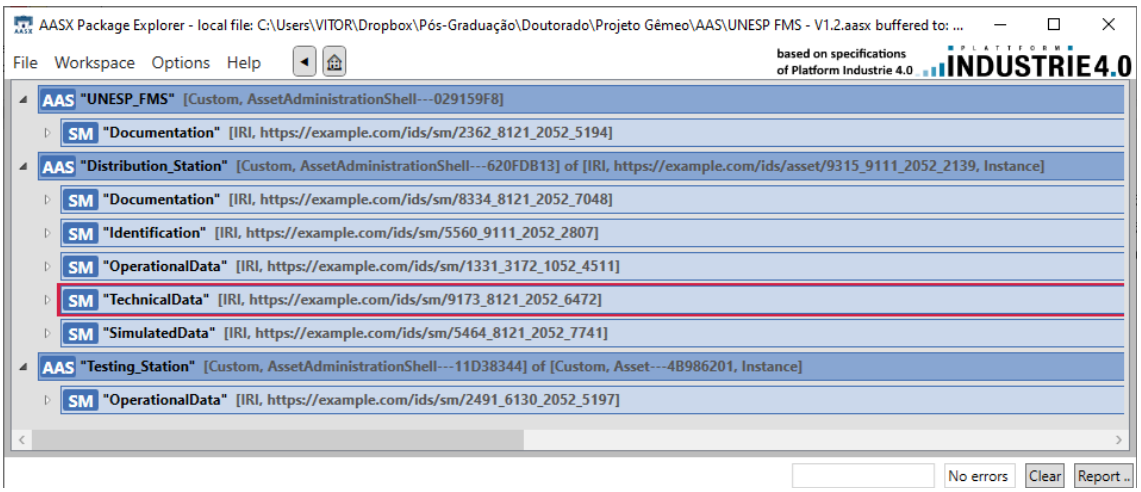

Figure 3: AAS Model (The Authors)

Once the file is created in the AAS environment, it is necessary to export it as an XML file so that the OPC UA Server embedded in Node-RED can read the file and create the necessary structure of files. To export the file, as shown in Figure 4, the OPC UA Nodeset2.xml extension is used.

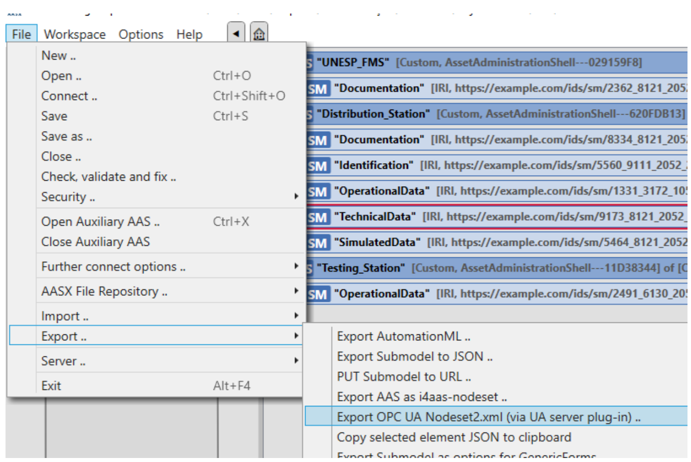

Figure 4: AAS File Export (The Authors)

[2] https://github.com/eclipse-aaspe/package-explorer

After loading the server on Node-RED, it is possible to see in OPC UA the full structure of the AAS Information Model. We detail that structure in Figure 5, based on what is viewed by the UAExpert Client[3] software. On the left-hand side you can see the full structure that AAS created, including all 3 Assets: Distribution Station, Testing Station and UNESP_FMS. On the right hand-side the structure of the "Operational Data" submodel is detailed, showing the sub-collections created to categorize the variables by type (Actuators, Control, Feedback and Sensors) and the actual variables of the Sensors Sub-collection.

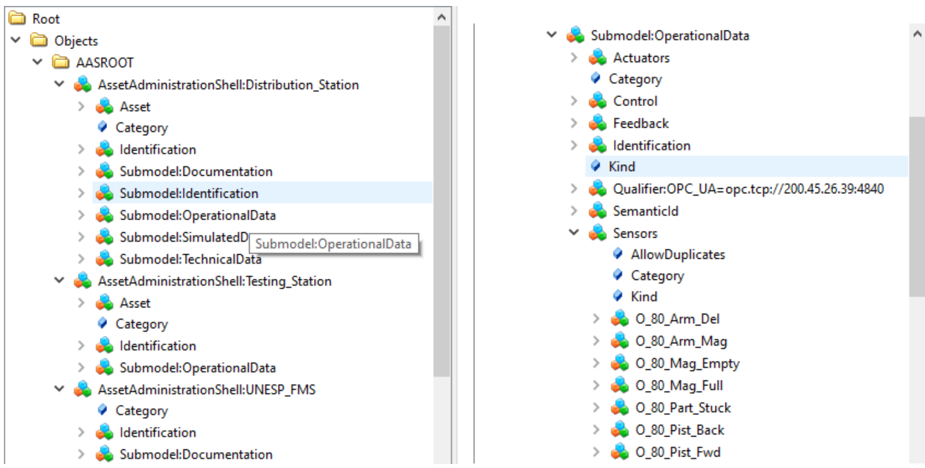

Figure 5: OPC-UA Server (The Authors)

It is important to notice that each asset, variable of specification has a unique identification (id). This value is assigned by AAS and can change if more information is added to the AAS Model. This presents a challenge as the values for the variables are no longer stored under a "string" variable that is user defined, but by a sequential and unique numeric value (the "id"). This presented an obstacle to the adoption of the AAS Model, as using the method described in previous works, specially Sousa et al., (2024), would not work. To overcome that obstacle a new solution to communicate to the variables was implemented as described in the section 3.2 below.

3.2 Node-RED and OPC UA Flows Update

In this section we will detail the updated Node-RED flows from the previous research (Sousa et al., 2024; Sousa & Caldana, 2023) for both the Server and the Stations flows. The upgrade was a necessity as described in Section 3.1

3.2.1 Server Flow

The server flow for AAS is very simple, with no other information needed rather than the OPC UA Server node. The simplification from early versions is due to the fact that all relevant information is now stored in the nodeset.xml file that was exported from the AAS Model. The file contains all the necessary information to create the AAS Namespace (ns=6) on the server with all the information that was shown in Section 3.1. The final server flow is shown in Figure 6 below.

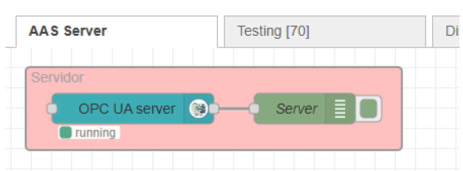

Figure 6: Server Flow(The Authors)

3.2.2 Station Flows

The station flows are divided into sections and groups. Each group handles a specific part of the information for each station. Even though the signals will vary for each station, the structure is very similar as it divides the information on

[3] https://www.unified-automation.com/products/development-tools/uaexpert.html

each station into the variable's topics. For the purpose of this paper, we will detail each type of interaction: the CSV file, the Actuators, the Sensors/Feedback and the Control variables.

The CSV file responsible for the translation of the variable names to the NameSpace/Identifier that the AAS Model creates is detailed in Figure 7 below. The first command line is responsible for creating the header of the CSV file, that has three columns: "Variable", "Namespace" and "Identifier". The second command line gets the all the variables from the station and, after the client is connected to the server, sends a reed request for each variable using the path provided by the AAS Model. By doing this, the AAS Read node will respond with the relevant information as well as the "Namespace" and "Identifier" for that specific variable. The flow then reorganizes the information and writes the information on the CSV file.

The third and fourth command lines are responsible for writing and subscribing (reading) the variables once the server is up. This ensures that changes from the PLC will be written in OPC UA database and if another client writes a value directly on the server this is passed on to the PLC´s, allowing for full duplex communication.

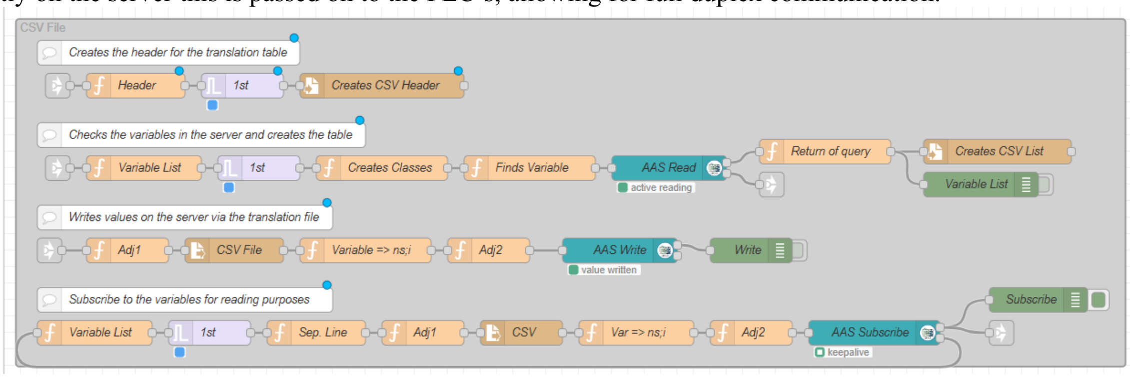

Figure 7: Station Flow – CSV File (The Authors)

The Actuators are responsible for triggering the outputs of the PLCs and are detailed in Figure 8 below. Information is inputted via the Dashboard and written on OPC UA (on the lefthand side). After it is written, the subscription process sends the signal back acknowledging the change to the switch node and to the PLC´s outputs (on the righthand side).

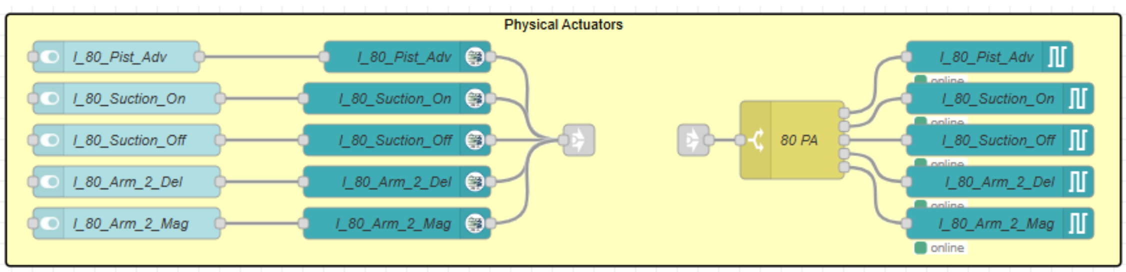

Figure 8: Station Flow – Actuators (The Authors)

The Sensors and Feedback are responsible for reading the inputs of the PLCs and are detailed in Figure 9 below. Information is inputted by reading the PLC signals and then written on OPC UA (on the lefthand side). After it is written, the subscription process sends the signal back acknowledging the change to the switch node and to Dashboard LED´s (on the righthand side).

The Controls are a mixture of inputs and outputs from and to the PLCs and are detailed in Figure 10 below. These signals are responsible for configuring the mode in which the stations will work. The Control signals being external to the PLC will allow, in the future, a MES system or another entity (such as the RFID sensors) to take control over what the station needs to perform during the production run, allowing for a true flexible line, even during production. The signals follow the same logic of the blocks described above for Actuators and Sensors.

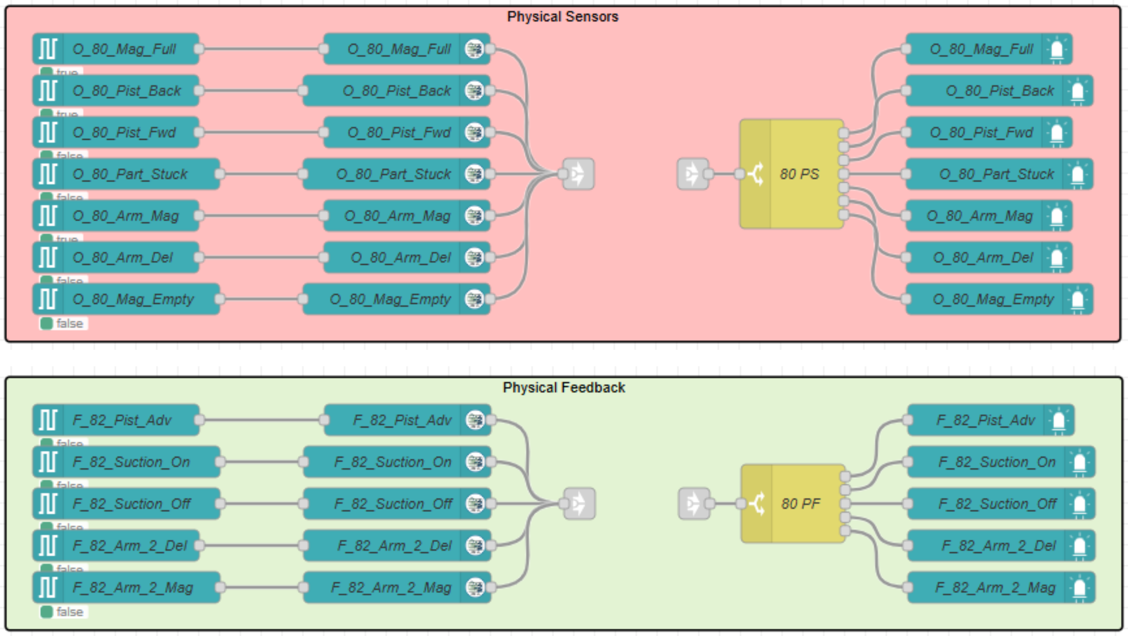

Figure 9: Station Flow – Sensors and Feedback (The Authors)

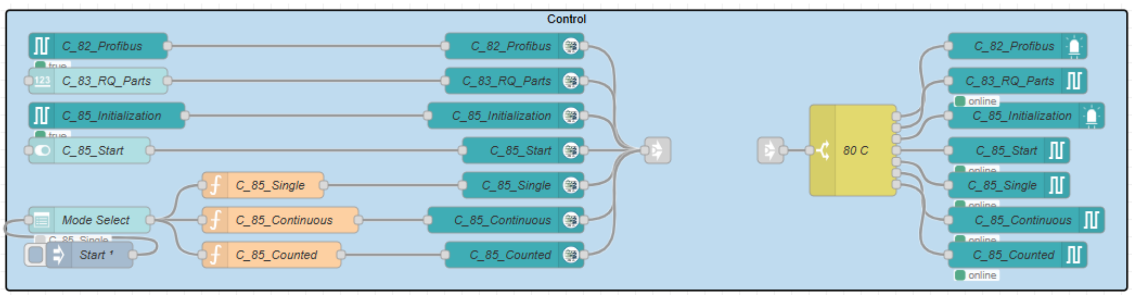

Figure 10: Station Flow Control (The Authors)

4 Development, Obstacles and Future Research

This research set out to establish if an AAS Information Model was possible to be adapted to a Legacy system. The first obstacle that was perceived was the extensive regulation and information available from IDTA. Though present to ensure the interoperability that is an important achievement, it took a significant amount of time to comprehend what was necessary and the presence of tools such as Eclipe´s AASX Explorer Package was fundamental in improving the knowledge of AAS as well as implementing the most common submodels.

It is still unclear, and will be the goal of future research, if making a centralized AAS for the complete FMS is the best route to be taken or if individual and more compartmentalized structure should be implementing, with the "mother" asset being the station itself and the smaller assets being the components inside the station. Even though this approach can give more details into each station itself it will need separated servers (one for each station) and this has to be taken into consideration when exploring a wider solution with the Digital Twin.

Type 1 AAS (static information) was easily integrated and for the purposes of the day-to-day production had little to no impact. With the addition of more information several procedures can be standardized, especially in the maintenance department, with test templates and information from last interventions. The gathering of this information should be looked at in future research.

Type 2 AAS was the most complex to be integrated, as it contained the Operational Data and Simulated Data. As discussed, the different method of identification provided by AAS for the variables demanded significant changes on the Node-RED programming to be able to read and write values. The reading of variables was particularly challenging and solved via the Subscribe command on the Server. A video was created detailing the solution via the Subscription feature of the OPC UA Client and is available at: https://youtu.be/u3HV8FkgoWk in Brazilian Portuguese.

The OPC UA Server node has limitations towards number of subscriptions and clients. This issue has been raised with the developer and a reply was not yet provided until this paper was finalized. If the limitations are kept, this would force individual creation of AAS by stations as the only feasible solution.

A new dashboard, developed for the AAS Model in Node-RED was developed and can be seen in

Figure 11 to show that for the end-user there is little to none difference to the previous versions of dashboard. With this, the end user will not be greatly affected by the new structure, proving that the upgrade to AAS and the new structure will provide a greater range of use of the information without impacting on the day-to-day operations.

Figure 11: AAS Node-RED Dashboard (The Authors)

5 Conclusion

The results of this work demonstrate that the modeling of the AAS can be successfully applied to legacy systems. The creation of submodels enabled a comprehensive digital representation of the asset, facilitating interoperability and information integration within an Industry 4.0 context. The integration with the OPC UA protocol was also successful, even though some obstacles still remain, allowing the submodels and their properties to be viewed directly within the OPC UA structure. With the results obtained so far it possible to affirm that AAS can be used as a Information Model for bridging the gap between Legacy Systems and Industry 4.0.

The CSV structure and the Subscribe solution to read the variables (that was needed on the previous versions without AAS) are the main contribution of this paper, as it was due to the implementation of this solution that it is now possible to say that we can create an AAS Model for a Legacy system and adapt it to an existing legacy structure by using Node-RED and OPC UA. This brings the Legacy System one step closer to the Industry 4.0 technology and its many advantages.

Future work in this area will continue, as the project is still under way. The main future focus will be adapting the Simulated Variables with MatLAB and the creation of a full Digital Twin with AAS for legacy systems. The integration of all stations and other equipment (such as the RFID Sensors and the Robotic Arm by Mitsubishi) is also intended.

Acknowledgements

This paper was developed in part by researches of the GPI4 Research Group[4]
This research was funded by grant 2024/21954-7, São Paulo Research Foundation (FAPESP).

References

Abdel-Aty, T. A., Negri, E., & Galparoli, S. (2022). Asset Administration Shell in Manufacturing: Applications and Relationship with Digital Twin. *IFAC-PapersOnLine*, *55*(10), 2533–2538. https://doi.org/10.1016/j.ifacol.2022.10.090

Bajic, B., Rikalovic, A., Suzic, N., & Piuri, V. (2021). Industry 4.0 Implementation Challenges and Opportunities: A Managerial Perspective. *IEEE Systems Journal*, *15*(1), 546–559. IEEE Systems Journal. https://doi.org/10.1109/JSYST.2020.3023041

Barbosa, J. P. P. [UNESP. (2024). *Modelagem da Informação usando Asset Administration Shell para um Sistema de Manufatura Flexível Legado*. https://hdl.handle.net/11449/258111

Barnstedt, E., Bedenbender, H., Billmann, M., Boss, B., Clauer, E., Fritsche, M., Garrels, K., Hankel, M., Hillermeier, O., Hoffmeister, M., Jochem, M., Koziolek, H., Legat, C., Mendes, M., Neidig, J., Sauer, M., Schier, M., Schmitt, M., Schröder, T., & Ziesche, C. (2018). *Details of the Asset Administration Shell. Part 1 – The exchange of information between partners in the value chain of Industrie 4.0 (Version 1.0)*.

Bitsch, G., Senjic, P., & Askin, J. (2023). Integration of Legacy Systems to Cyber-Physical Production Systems using Semantic Adapters. *Procedia CIRP*, *118*, 259–263. https://doi.org/10.1016/j.procir.2023.06.045

Cavalieri, S., & Salafia, M. G. (2020). Asset Administration Shell for PLC Representation Based on IEC 61131–3. *IEEE Access*, *8*, 142606–142621. IEEE Access. https://doi.org/10.1109/ACCESS.2020.3013890

Clerissi, D., Leotta, M., Reggio, G., & Ricca, F. (2018). Towards an approach for developing and testing Node-RED IoT systems. *Proceedings of the 1st ACM SIGSOFT International Workshop on Ensemble-Based Software Engineering*, 1–8. https://doi.org/10.1145/3281022.3281023

IDTA. (2025). *IDTA - AAS Submodel Templates*. IDTA. https://industrialdigitaltwin.org/en/content-hub/submodels

Inigo, M. A., Porto, A., Kremer, B., Perez, A., Larrinaga, F., & Cuenca, J. (2020). Towards an Asset Administration Shell scenario: A use case for interoperability and standardization in Industry 4.0. *NOMS 2020-2020 IEEE/IFIP Network Operations and Management Symposium*, 1–6. https://ieeexplore.ieee.org/abstract/document/9110410/

Kutscher, V., Olbort, J., Anokhin, O., Bambach, L., & Anderl, R. (2020). Upgrading of legacy systems to cyber-physical systems. *Proceedings of TMCE 2020*. https://www.researchgate.net/profile/Vladimir-Kutscher/publication/346315936_UPGRADING_OF_LEGACY_SYSTEMS_TO_CYBER-PHYSICAL_SYSTEMS/links/5fbe3ba8458515b7976b02c5/UPGRADING-OF-LEGACY-SYSTEMS-TO-CYBER-PHYSICAL-SYSTEMS.pdf

Mahnke, W., Leitner, S.-H., & Damm, M. (2009). *OPC Unified Architecture*. Springer. https://doi.org/10.1007/978-3-540-68899-0

Marcon, P., Diedrich, C., Zezulka, F., Schröder, T., Belyaev, A., Arm, J., Benesl, T., Bradac, Z., & Vesely, I. (2018). The Asset Administration Shell of Operator in the Platform of Industry 4.0. *2018 18th International Conference on Mechatronics - Mechatronika (ME)*, 1–5. https://ieeexplore.ieee.org/document/8624699

Quadrini, W., Cimino, C., Abdel-Aty, T. A., Fumagalli, L., & Rovere, D. (2023). Asset Administration Shell as an interoperable enabler of Industry 4.0 software architectures: A case study. *Procedia Computer Science*, *217*, 1794–1802. https://doi.org/10.1016/j.procs.2022.12.379

[4] http://dgp.cnpq.br/dgp/espelhogrupo/350090

Rikalovic, A., Suzic, N., Bajic, B., & Piuri, V. (2022). Industry 4.0 Implementation Challenges and Opportunities: A Technological Perspective. *IEEE Systems Journal*, *16*(2), 2797–2810. IEEE Systems Journal. https://doi.org/10.1109/JSYST.2021.3101673

Schwab, K. (2019). *A Quarta Revolução Industrial*. EDIPRO.

Siatras, V., Bakopoulos, E., Mavrothalassitis, P., Nikolakis, N., & Alexopoulos, K. (2023). On the Use of Asset Administration Shell for Modeling and Deploying Production Scheduling Agents within a Multi-Agent System. *Applied Sciences*, *13*(17), Artigo 17. https://doi.org/10.3390/app13179540

Sousa, D. R. de, Caldana, V., & Godoy, E. P. (2024, maio 7). *Upgrading legacy systems for Industry 4.0 with Node-RED and OPC-UA*. 5th South American Industrial Engineering and Operations Management Conference. https://doi.org/10.46254/SA05.20240068

Sousa, D. R. de, & Caldana, V. M. (2023). Node-RED for PLC Automation. *Proceedings of the 4th South American International Industrial Engineering and Operations Management Conference*.

Steinmetz, C., Schroeder, G. N., Sulak, A., Tuna, K., Binotto, A., Rettberg, A., & Pereira, C. E. (2022). A methodology for creating semantic digital twin models supported by knowledge graphs. *2022 IEEE 27th International Conference on Emerging Technologies and Factory Automation (ETFA)*, 1–7. https://ieeexplore.ieee.org/document/9921499/

Stolze, M., Belyaev, A., Kosel, C., Diedrich, C., & Barnard, A. (2024). Realizing Automated Production Planning via Proactive AAS and Business Process Models. *2024 IEEE 29th International Conference on Emerging Technologies and Factory Automation (ETFA)*, 1–8. https://doi.org/10.1109/ETFA61755.2024.10710731

Tantik, E., & Anderl, R. (2017). Integrated Data Model and Structure for the Asset Administration Shell in Industrie 4.0. *Procedia CIRP*, *60*, 86–91. https://doi.org/10.1016/j.procir.2017.01.048

Xavier, A. B., Candido, K. H. F., Roberto, J. C. A., & Souto, S. P. (2023). A automação industrial como solução e não como ameaça aos trabalhadores. *GeSec : Revista de Gestão e Secretariado*, *14*(6), 9019–9032. https://doi.org/10.7769/gesec.v14i6.2278

ZVEI. (2015). *GMA Status Report: Reference Archtitecture Model Industrie 4.0 (RAMI 4.0)*. https://www.zvei.org/en/press-media/publications/gma-status-report-reference-archtitecture-model-industrie-40-rami-40

ZVEI. (2016). *Examples of the Asset Administration Shell for Industrie 4.0 Components – Basic Part*. ZVEI. https://www.zvei.org/en/press-media/publications/examples-of-the-asset-administration-shell-for-industrie-40-components-basic-part

Biography

Vitor Mendes Caldana began his career with a technician course in Electronics from Liceu de Artes e Ofícios in 1999, followed by an undergraduate degree in Electronic Engineering from Universidade Presbiteriana Mackenzie in 2004. In 2016, finished his M.Sc. in Industrial Engineering. Since 2023 is a student at UNESP to obtain his Ph.D. in Electronic Engineering in the Industry 4.0 field. In 2014 began his teaching career in FIEB as a substitute teacher, followed by an associate professor position for the Technical Course of Electronics. In 2016 became a full-time professor by joining IFSP, moving to the Sorocaba Campus to implement the Electronics High-School Technical Course. In 2018 started the Research Group in Industry 4.0 at IFSP and has been its leader since. Between 2019 and 2020, along with his colleagues, designed and implemented the first Post-Graduate Program in Industry 4.0 of IFSP at the Sorocaba Campus. He is currently involved in research projects in Industry 4.0. http://lattes.cnpq.br/8361188962318020

João Paulo Pinheiro Barbosa is a student with a background in scientific research on thin films for perovskite solar cells and practical experience in networking and electronic security systems, particularly with IP cameras. He is passionate about applying his technical skills in real-world settings, with a focus on automation, Industry 4.0, and renewable energy technologies. His career goals include contributing to innovations in industrial automation and sustainable energy solutions.

Eduardo Paciencia Godoy received the B.Eng. degree in Control and Automation Engineering at Itajubá Federal University (MG-Brazil) in 2003 and the M.Sc. and Ph.D. degrees in Mechanical Engineering at University of São Paulo (SP-Brazil) in 2007 and 2011. Currently he is an Associate Professor of Unesp (SP-Brazil) with research interests in IoT and Industry 4.0. http://lattes.cnpq.br/0072632067545698.