Cloud Data Sharing for the Integration of Heterogeneous Systems for Personalized Production

Paulo Henrique Farias de Carvalho Filho[1*], João Vitor Mendes Pinto do Santos[2], Thamiles Rodrigues de Melo[2], Herman Augusto Lepikson[1,2]

[1]Post-Graduation Program in Mechatronics (PPGM), Federal University of Bahia (UFBA); [2]SENAI CIMATEC University; Salvador, Bahia, Brazil

The increasing demand for customized products poses significant challenges for companies aiming to optimize logistics and manufacturing operations. Multiple companies within a supply network—each using distinct information systems—must be coordinated from order negotiation to the end of the product life cycle. This challenge involves the integration of heterogeneous systems and the harmonization of data across all sectors of the manufacturing chain. This study proposes cloud-based data sharing to establish seamless communication among distributed information systems. The proposed approach was implemented in two pilot plants supported by advanced Industry 4.0 systems. The analysis indicates that this method facilitates effective data sharing in customer-supplier relationships, thereby improving the coordination and scheduling of production activities.
Keywords: Discrete Manufacturing. Integration of Heterogeneous Systems. Cloud Computing. Distributed Manufacturing. Industry 4.0.

The growing demand for personalized products is driven by increasingly discerning consumers seeking items tailored to their specific preferences and needs. This trend spans several sectors, including fashion, electronics, and automotive industries [1,2]. Consequently, discrete manufacturing companies are under pressure to swiftly adapt factory operations to meet the demand for customized products and navigate volatile market conditions [3].

Personalized production requires integrated systems that facilitate data flow across the various stages and components of a globally distributed production process. Data integration enables seamless communication among heterogeneous systems companies to use in different geographic locations. Data from diverse sources must be shared, processed, and analyzed in real-time to ensure adequate production planning and management.

Beyond enabling integration, sharing information throughout the manufacturing chain enhances collaboration among systems, equipment, and devices. This creates opportunities to coordinate and fine-tune operations in response to shifting market demands. However, integrating distributed systems remains a significant challenge due to a lack of practical tools for managing distributed manufacturing chains [4].

This article proposes a solution for integrating information and process flows across different production chain segments. This approach is essential for addressing the challenges of discrete manufacturing companies in today's dynamic environment. The paper is structured as follows: Section 2 presents the literature review, Section 3 details the methodology and implementation, Section 4 discusses the results, and Section 5 provides the conclusions.

Literature Review

Discrete manufacturing—focused on producing distinct, individual units—has gained renewed importance due to the Industry 4.0 paradigm, which promotes a shift from centralized to more flexible and globally distributed operations [1]. Although implementing this global model remains in progress, companies must contend with increasing product complexity, stricter quality standards, and greater variety in unit products [5].

Received on 21 January 2025; revised 30 March 2025.
Address for correspondence: Paulo Henrique Farias de Carvalho Filho. Rua Prof. Arístides Novis, 2 - Federação. Salvador, Bahia, Brazil. Zipcode: 40170-110. E-mail: paulofarias@ufba.br.

J Bioeng. Tech. Health 2025;8(2):157-162

The evolving manufacturing profile reflects a more substantial consumer influence, necessitating ongoing adaptation to shifting demands. This includes integrating and sharing data among distributed organizations involved in product development and delivery [4]. The need for newer and more personalized products intensifies the demand for efficient integration and seamless information exchange throughout the production chain.

Nonetheless, the literature offers limited tools for achieving this goal, as synchronous data integration among companies remains uncommon. Integrating heterogeneous systems—facilitated through cloud-based data sharing—is essential for preparing and managing information and process flows, ultimately supporting efficient production planning.

Cloud Data Sharing for Heterogeneous Systems Integration

Extensive research has been devoted to enhancing manufacturing systems' intelligence, flexibility, and service orientation to support collaborative discrete production within distributed networks. Cloud manufacturing stands out for its ability to deliver on-demand services, aggregating manufacturing resources into a network accessible via the cloud. These services can be configured and integrated rapidly to fulfill distributed production orders [6]

According to Ren and colleagues [7], cloud computing comprises three primary service models. Infrastructure as a Service (IaaS) provides hardware resources such as computing power, storage, and networks—via physical or virtual machines—enabling users to customize their IT infrastructure. Platform as a Service (PaaS) offers a development environment for cloud services, while Software as a Service (SaaS) allows users to access applications directly over the Internet.

Lu, Xu, and Wang [8] emphasize that cloud-based equipment-as-a-service can be integrated directly into digital manufacturing networks. In this context, physical assets are connected to cyber-physical systems (CPS) using standardized communication protocols such as OPC UA and MTConnect. Application Programming Interfaces (APIs) are pivotal in ensuring secure and standardized communication between components.

OPC UA was selected as the communication protocol for this work due to its security, stability, and widespread industrial adoption. Furthermore, CPS can be integrated directly into Manufacturing Execution Systems (MES), enabling more effective coordination and scheduling of production activities [8]. The cloud-based data-sharing approach proposed in this study is predicated on developing a cloud communication infrastructure that ensures the reliable and efficient exchange of information between diverse production systems.

MES 4.0

The MES manages production information from order placement to product completion [5]. In discrete manufacturing, such information must be acquired through integrating heterogeneous systems, real-time data sharing, and analysis from distributed companies. MES plays a central role in transforming industrial processes to meet the demands of Industry 4.0.

Shojaeinasab and colleagues [9] argue that an MES designed with Industry 4.0 capabilities can handle large volumes of data (big data) and extract valuable insights about various production dimensions. These insights can be used to identify patterns and trends and support decision-making regarding production tasks. NoSQL databases perform exceptionally well with real-time data, such as quality checks requiring continuous updates [10]. In this study, data sharing between distributed companies forms the basis for an enhanced version of MES, which can deliver personalized analyses and insights into manufacturing operations.

Materials and Methods

The key elements and gaps in the existing literature were identified to formulate a coherent research hypothesis. According to Gil [11], a systematic review must address hypothesis formulation and problem familiarization to enhance clarity. The method adopted in this work also aligns with the guidelines of Gerhardt and Silveira [12], who emphasize generating specific knowledge applicable to practical scenarios. Accordingly, this study aims to implement cloud-based data sharing for heterogeneous systems to improve personalized production services. This work's development leveraged the infrastructure of the Advanced Manufacturing Plant (AMP) and Model Factory (MF) laboratories located at SENAI CIMATEC in Salvador. The MF focuses on producing pneumatic cylinders, while the AMP supports customized base-part production for the MF. The proposed cloud-based integration aims to facilitate real-time information exchange between these two environments, enhancing the responsiveness and coordination of production services.

Figure 1 illustrates the architecture of the proposed integration framework. The data flow outlined in this architecture is incorporated into MES 4.0 to ensure efficient production process management.

API Middleware Architecture

An API middleware architecture was developed to enable the integration of heterogeneous systems. This software architecture is illustrated in Figure 2. The application logic is divided into three main components:

- **AmpFacadeAPI:** This component acts as a wrapper for the AMP MES API routes and leverages the functionalities of MES 4.0. Its primary role is to receive customer order requests, validate their integrity, forward them to the AMP system, and relay the responses to the MF system.
- **SecurityController:** This module verifies whether the user submitting the order request has the appropriate authorization to interact with the AMP system.
- **LogHandler:** Responsible for logging all relevant activities within the API process, ensuring traceability and system observability.

The middleware was developed using Node.js in conjunction with the TypeScript programming language. The Express.js framework was utilized to build the RESTful API endpoints, while the Winston library was adopted for structured logging. All logs are stored in a Cassandra NoSQL database, which includes a dedicated table for log entries.

A key aspect of the logging strategy is using log levels, which support the classification and prioritization of recorded events for troubleshooting

Figure 1. Integration AMP and MF.

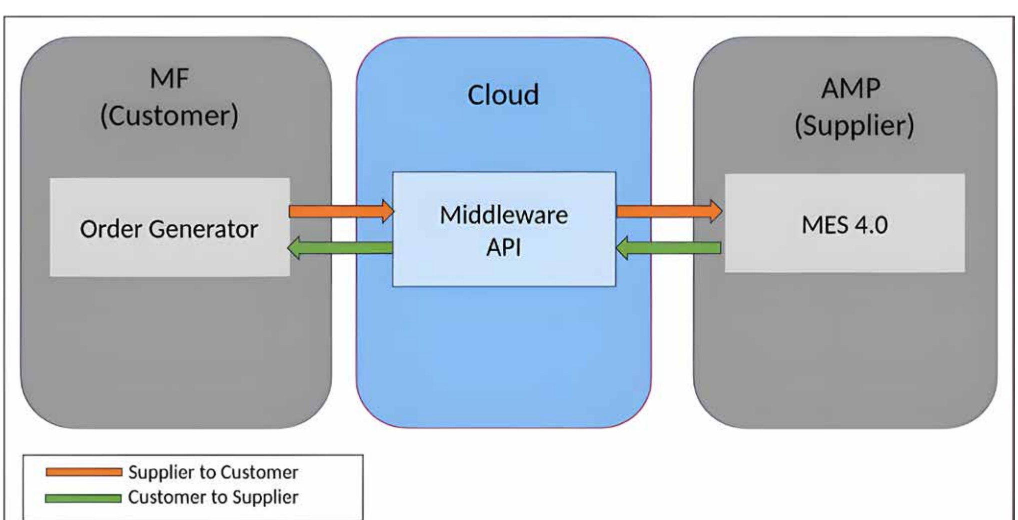
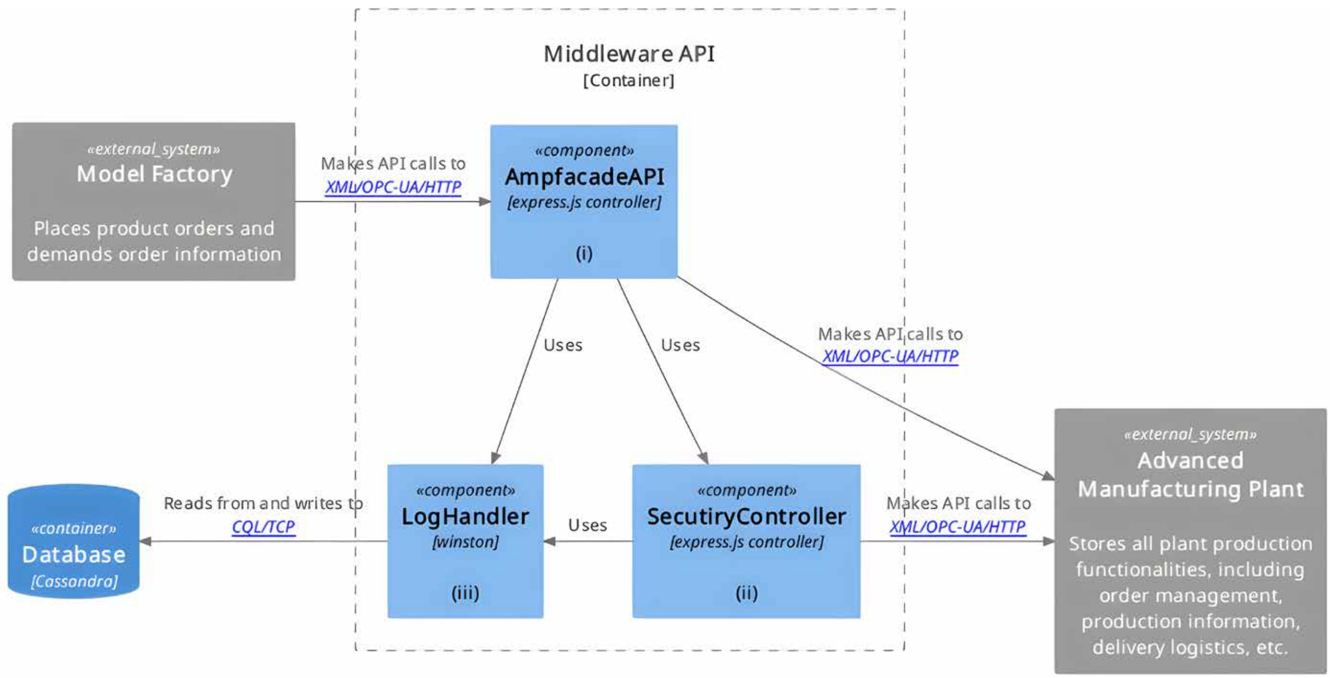


Figure 2. Integration API architecture.



and performance analysis. The three defined levels are:

- **Info:** Used for logging routine operations and process outcomes.
- **Error:** Records issues that impact application performance or flow.
- **Fatal:** Captures critical failures that may interrupt or halt the application.

Each log level is associated with a distinct data retention policy, ensuring that only relevant information is preserved long-term for audit trails and quality assessments.

Results and Discussion

The effectiveness of the cloud-based integration using the middleware was validated by successfully transferring customer orders. The order generator system sent customer requests to the supplier, which were successfully received and registered in the AMP production queue, as shown in Figures 3 and 5. In contrast, Figure 4 illustrates a failed order request due to the absence of valid user credentials, a controlled scenario designed to test system robustness.

These results confirm the expected behavior of the AmpFacadeAPI and SecurityController components under both normal and exception conditions. The integration architecture enables improved digital traceability and real-time monitoring capabilities, enhancing responsiveness and operational efficiency in customer order processing and production management.

The LogHandler component also met the expected behavior by recording transaction information between systems and all interactions involving other components in the Cassandra database, as illustrated in Figure 6. This robust data capture facilitates AI's use for predictive analytics and decision-making and enhances demand forecasting capabilities.These insights enable a deeper understanding of production patterns and trends, supporting strategic planning and operational efficiency.

Conclusion

This work presents a state-of-the-art approach to data sharing and integrating heterogeneous systems in distributed personalized production.

Figure 3. Order Request successful - Code 200.

Figure 4. Order Request unsuccessful - Code 403.

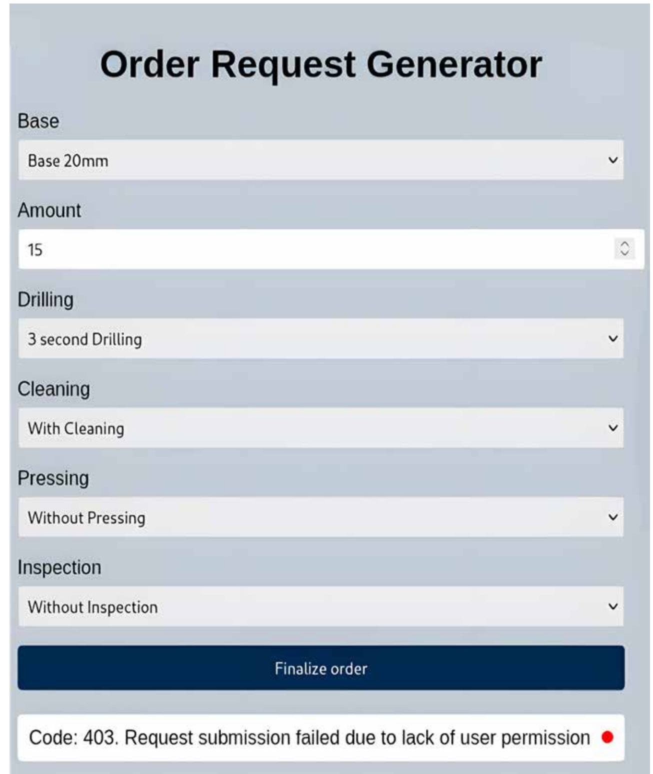
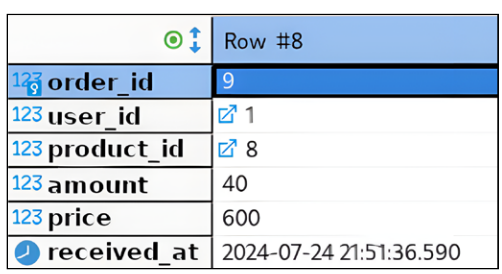
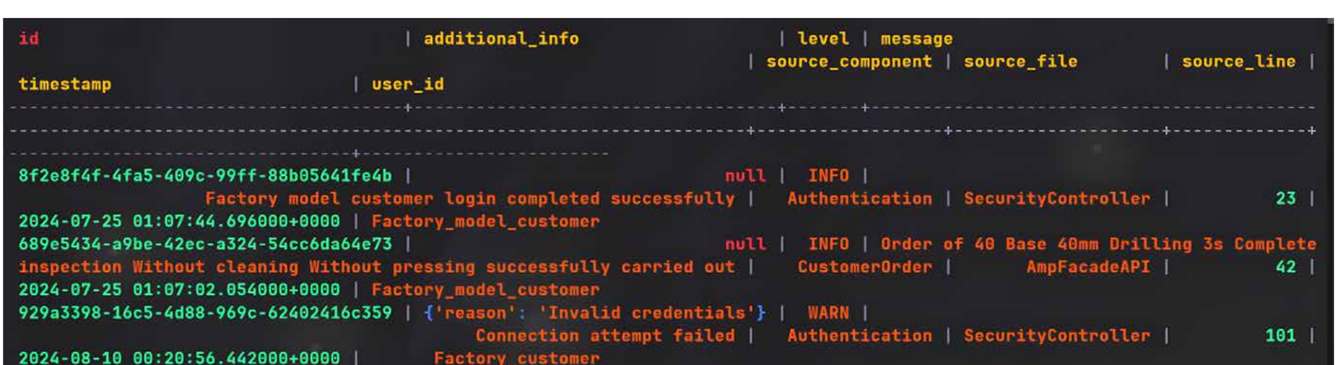


Figure 5. Registration of the requested order in AMP's internal database.



	Row #8
order_id	9
user_id	1
product_id	8
amount	40
price	600
received_at	2024-07-24 21:51:36.590

Figure 6. Result of integration into AMP's MES.



```
id                                   | additional_info                      | level | message
                                                                   | source_component | source_file          | source_line |
timestamp                        | user_id
8f2e8f4f-4fa5-409c-99ff-88b05641fe4b |                                 null |  INFO |
                  Factory model customer login completed successfully |   Authentication | SecurityController |          23 |
2024-07-25 01:07:44.696000+0000 | Factory_model_customer
689e5434-a9be-42ec-a324-54cc6da64e73 |                                 null |  INFO | Order of 40 Base 40mm Drilling 3s Complete
inspection Without cleaning Without pressing successfully carried out |    CustomerOrder |        AmpFacadeAPI |          42 |
2024-07-25 01:07:02.054000+0000 | Factory_model_customer
929a3398-16c5-4d88-969c-62402416c359 | {'reason': 'Invalid credentials'} |  WARN |
                                             Connection attempt failed |   Authentication | SecurityController |         101 |
2024-08-10 00:20:56.442000+0000 |       Factory_customer
```

Key challenges addressed include the lack of effective tools for integrating and synchronizing data across geographically dispersed enterprises and the need to ensure data harmonization throughout the production chain.

The proposed method involves cloud-based data sharing, from customer order intake through supplier integration, enabling seamless information flow across the various stages of production. This flow is integrated into a new iteration of the Manufacturing Execution System (MES), designed to support the requirements of Industry 4.0. The solution was validated in two educational pilot plants simulating a pneumatic cylinder production scenario: the Advanced Manufacturing Plant (AMP), responsible for the customized production of bases and covers, and the Model Factory (MF), which performs final cylinder assembly.

The results demonstrate that the developed approach supports the efficient management of a discrete manufacturing chain by maintaining consistent and reliable data flow in a customer-supplier context. Despite these positive outcomes, further research is necessary, particularly to address challenges such as system latency due to high transaction volumes and cybersecurity concerns related to handling sensitive production data.

Acknowledgments

The authors would like to thank the Bahia State Research Support Foundation (FAPESB) for funding this study and the Integrated Manufacturing and Technology Center (SENAI-CIMATEC) for providing access to the Advanced Manufacturing Plant (AMP) and Model Factory (MF) laboratories used in the experimental implementation of this research.

References

1. Helu M, Hedberg T, Camelio J, Dornfeld D. Industry review of distributed production in discrete manufacturing. J Manuf Sci Eng. 2020;142(11).
2. Pech M, Vrchota J. The product customization process in relation to industry 4.0 and digitalization. Processes. 2022;10(3):539.
3. Wang Y, Ma H, Yang C, Wang K. Industry 4.0: a way from mass customization to mass personalization production. Adv Manuf. 2017;5(4):311–20.
4. Valilai OF, Houshmand M. A collaborative and integrated platform to support distributed manufacturing system using a service-oriented approach based on cloud computing paradigm. Robot Comput Integr Manuf. 2013;29(1):110–27.
5. Chen X, Voigt T. Implementation of the Manufacturing Execution System in the food and beverage industry. J Food Eng. 2020;278:109932.
6. Lu Y, Xu X. Cloud-based manufacturing equipment and big data analytics to enable on-demand manufacturing services. Robot Comput Integr Manuf. 2019;57:92–102.
7. Ren L, Zhang L, Wang L, Tao F, Chai X. Cloud manufacturing: key characteristics and applications. Int J Comput Integr Manuf. 2017;30(6):501–15.
8. Lu Y, Xu X, Wang L. Smart manufacturing process and system automation–a critical review of the standards and envisioned scenarios. J Manuf Syst. 2020;56:312–25.
9. Shojaeinasab A, Azadegan A, Daryaei AA, Ghezavati VR, Ghods S. Intelligent manufacturing execution systems: A systematic review. J Manuf Syst. 2022;62:503–22.
10. Santos MY, Costa CJ, Costa E, Meirinhos M, Martins JM, Galvão JR. A Big Data system supporting Bosch Braga Industry 4.0 strategy. Int J Inf Manag. 2017;37(6):750–60.
11. Gil AC. Como elaborar projetos de pesquisa. 4. ed. São Paulo: Atlas; 2002.
12. Gerhardt TE, Silveira DT. Métodos de pesquisa. Porto Alegre: Editora da UFRGS; 2009.