Challenges in the systems integration process in naval units. Case study: Data Distribution Unit Project

Desafíos en el proceso de integración de sistemas en unidades navales. Caso de estudio: Proyecto Unidad de Distribución de Datos

DOI: https://doi.org/10.25043/19098642.246

Francisco Guevara [1]
Ronald López [2]
Willy Ramos [3]
Sergio Mendoza [4]
Stefany Marrugo [5]

Abstract

This article presents the challenges faced by the Research and Development Department of COTECMAR in the process of systems integration in naval units. For this purpose, it is used as a case study, the project through which a Data Distribution Unit (DDU) designed for ships of the Colombian Navy was developed and implemented. The methodology implemented for the development of the DDU is shown in summary form, with special emphasis on the implementation and testing phase; likewise, the main drawbacks identified and the most relevant lessons learned related to the integration of hardware and software modules that make up the DDU are presented. In this sense, it was found that in about 30% of the cases, the novelties or difficulties that arose, especially in the software implementations, were due to inaccurate information from the original manufacturers' manuals and undocumented updates. Finally, recommendations are made to improve onboard systems integration processes.
Key words: Data Distribution Unit (DDU), systems integration, naval systems.

Resumen

Este artículo presenta los desafíos que enfrenta el Departamento de Investigación y Desarrollo de COTECMAR en el proceso de integración de sistemas en unidades navales. Para ello, se emplea como caso de estudio, el proyecto mediante el cual se desarrolló e implementó una Unidad de Distribución de Datos (DDU) diseñada para buques de la Armada de Colombia. Se muestra de forma resumida la metodología implementada para el desarrollo de la DDU, haciendo especial énfasis en la fase de implementación y pruebas; así mismo, se presentan los principales inconvenientes identificados y las lecciones aprendidas más relevantes, relacionadas con la integración de los módulos de hardware y software que componen la DDU. En este sentido, se encontró que en alrededor del 30% de los casos, las novedades o dificultades que se presentaron, especialmente en las implementaciones de software, obedecieron a información imprecisa de manuales de los fabricantes originales y actualizaciones no documentadas. Finalmente, se emiten recomendaciones orientadas a mejorar los procesos de integración de sistemas a bordo.
Palabras claves: Unidad de Distribución de Datos (DDU), Integración de sistemas, sistemas navales.

Date Received: October 29th, 2022 - *Fecha de recepción: 29 de octubre de 2022*
Date Accepted: February 16th, 2023 - *Fecha de aceptación: 16 de febrero de 2023*

[1] R&D Department - COTECMAR. Email: fguevara@cotecmar.com
[2] R&D Department - COTECMAR. Email: rlopez@cotecmar.com
[3] R&D Department - COTECMAR. Email: wrramos@cotecmar.com
[4] R&D Department - COTECMAR. Email: smendoza@cotecmar.com
[4] R&D Department - COTECMAR. Email: smarrugo@cotecmar.com

Introduction

The frigate type units of the Colombian Navy's Almirante Padilla class have a Data Distribution Unit (DDU), whose function is to concentrate and integrate the signals obtained from the ship's navigation sensors and, subsequently, distribute them to other sensors and systems that require them for the fulfillment of their mission.

The "Data Distribution Unit" (DDU) that these units currently have was developed during the execution of the modernization process of the Almirante Padilla class frigates Plan ORION (between 2009 - 2011), in order to replace the old and obsolete navigation data retransmission module, known as RTU, which was in charge of receiving and retransmitting the analog signals from the navigation systems to the ship's equipment and systems that required them. With the change in technology from analog to digital, both in the sensors that produce/generate the information and in the equipment or systems that consume or require that information, the need to replace the previous system materialized [1].

The DDU allows centralizing the input signals from the navigation sensors, managing the distribution of the original data from each sensor, monitoring the input data and providing multiple outputs, in different serial and analog formats, proprietary or standard for the different equipment or systems that require such navigation data for their operation [1]. Similarly, the DDU is designed to be redundant, in terms of data availability of different variables and the operation of its internal components. Consequently, the main critical elements of the system include backup capability [2].

COTECMAR, as a Science and Technology Corporation, in its role of contributing to the development of capabilities for the Colombian Navy, led the execution of a research project in the field of systems integration in naval units, consisting of the development of a Data Distribution Unit (DDU) prototype; this project represented an important technological and technical challenge, which allowed strengthening capabilities and acquiring knowledge, which is reflected in a functional DDU prototype that was tested in the laboratory and on board an Almirante Padilla Class frigate.

This paper presents the development process carried out by COTECMAR to obtain a functional DDU prototype and the main challenges faced during the execution of projects of this nature on board naval units.

Solution design

The main objective of the Prototype of a Data Distribution Unit (DDU) for the Frigate type units of the Admiral Padilla class of the Colombian Navy was to integrate the data from the ship's navigation sensors for its distribution to the navigation, surveillance, command and control and/or armament equipment/systems that require it. Such objective would be achieved by receiving the information delivered by the unit's sensors, its management/storage and subsequent distribution [3]. From the system requirements analysis, the DDU Prototype requires the following main hardware components:

- Processing units: responsible for the execution of all the system's software modules, which process the data received from the sensors (Navigation Data Producers - NDP's), generate the data frames required by the equipment/consumer systems (Navigation Data Consumers - NDC's) and execute the additional system control tasks. The prototype was designed with two processing units to ensure redundancy in the operation of the system.
- Physical interfaces: Set of components whose function is to connect to the data output ports of the sensors and deliver the data frames to the processing units, ensuring that each unit receives the same information from the sensors. They must also perform the reverse process and connect to the data input ports of the consuming equipment/systems and deliver the required information. These components must perform the conversion of the signals received

from the physical ports of the sensors, so that they can be read by the interface peripherals of the processing units.

- Network connection: Allows interconnecting in a data network the different components of the system, such as the processing units, the data display unit, the physical interfaces, among others.
- Data visualization: Component that allows displaying the Graphic Interface or HMI of the system, for interaction with the operator through visualization and operation tasks.
- Power supply: Set of equipment and accessories whose function is to supply the power required by the different components of the system. For the design, redundancy in the power supply components is considered [4].

Regarding the software components required for the implementation of the prototype, the main modules are described below:

- Interfaces: It is the software module in charge of receiving information from the navigation sensors from the external interfaces and, subsequently, sending such information to the equipment/systems that require it. It is composed of the following sub-modules: Interface for receiving data from the ship's navigation sensors (IF Rx), Interface for transmitting navigation data to the systems/ equipment that require it in the established format and/or protocol (IF Tx).
- Processing: This is the software module in charge of storing and organizing the information obtained from the sensors. It is composed of the following sub-modules: Coordinator (in charge of supervising the execution and initialization of the different modules and/or software sub-modules), Supervisor (in charge of controlling the data manager, to guarantee the operation of the system according to the operation mode selected by the operator) and Data Manager (in charge of keeping the navigation information received from the ship's sensors dynamically stored, for its later distribution to the receiving equipment).
- HMI: It is the human-machine interface software module, where the operator will be able to visualize the navigation data values, manage the system configurations and monitor and control the system. It is composed of a presentation submodule (in charge of displaying the information received from the ship's sensors and the system status) and another one for configuration/control (its function is to interact with the operator to establish the configurations of the operation modes to be used).
- Messaging: The means by which different software modules (and sub-modules) can exchange information with each other [6].
- Security: This module is transversal to those described above, and includes aspects ranging from the management of network switch ports, through frame validation mechanisms, to the application of functionalities in the HMI to generate user profiles and protect the level of access that an operator would have to the system.

Fig. 1 shows the general software architecture for the DDU Prototype, including the modules and sub-modules described.

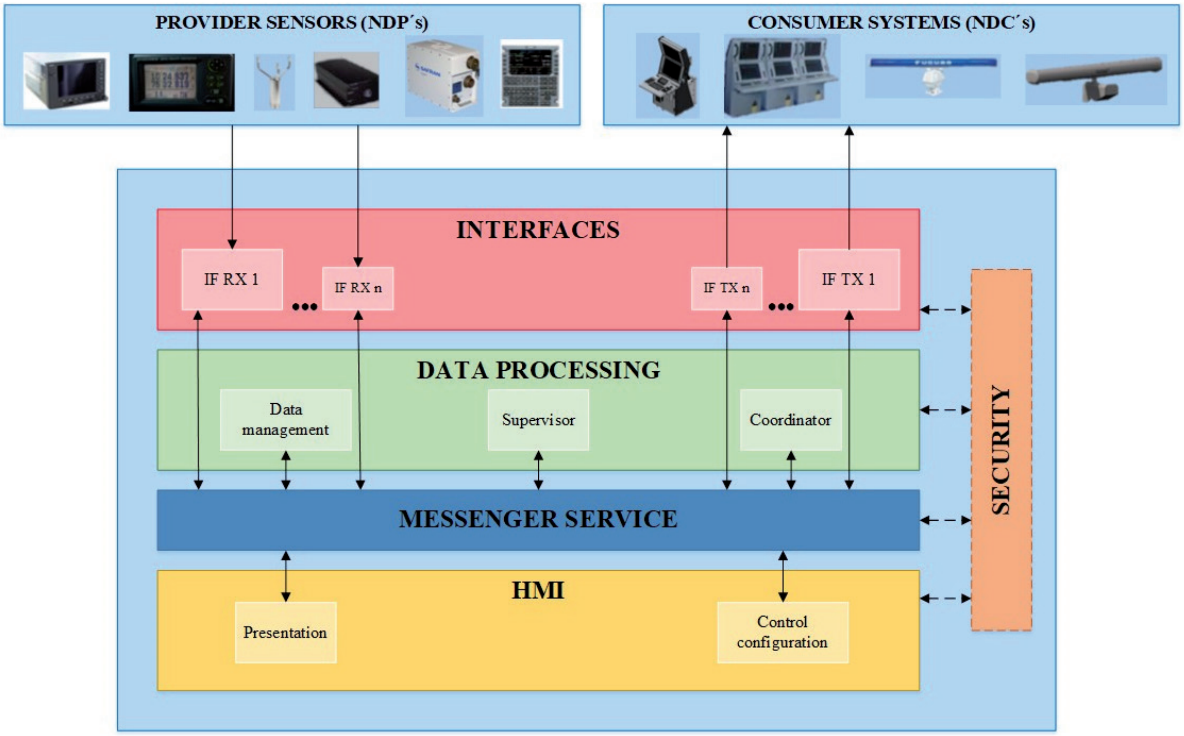
Implementation and testing

The implementation of the design foreseen for the DDU prototype implied the development of several technical information gathering activities on board the ARC Almirante Padilla class frigates. The technical staff of the weapons and electronics department of the ARC Bolivar Naval Base and the support of the units' crews assisted in this process.

As a result of the surveys and review of manuals, 16 links were identified between the existing DDU and its navigation data producers/consumers. These can be derived in sub-links, depending on the equipment that is connected. Likewise, some of the integrated signals are high frequency, so they will require specialized hardware for their processing.

On the other hand, the supply of hardware required for the implementation of the DDU prototype

Fig. 1. General software architecture for the DDU prototype [7].



developed by COTECMAR, is composed, among other equipment and accessories, by the following items:

- Processors.
- Human-Machine Interfaces.
- Devices for input/output signal management.
- Serial data servers.
- Environmental monitoring modules.
- UPS sources.
- AC and DC power distribution units.
- Ventilation modules.
- Standard 19' rack.
- Wiring, connectors and pins between equipment for internal and external interfaces (in laboratory).

Fig. 2 presents the front view of the implemented DDU prototype. In the image, the different hardware modules described in section 2 can be identified.

With a view to validate the software and hardware developments of the DDU prototype, a testing protocol was executed, which took place in the laboratory of the R&D department of COTECMAR. The test protocol was divided into test cases [8], as follows:

- Test case 1. Visual inspection of components. In this section the hardware components of the prototype were validated, verifying quantities, references, manufacturers, part numbers and the identification numbers assigned in the design process to each component. Likewise, the wiring of the connection interfaces between the components was validated.
- Test case 2. Start-up of the DDU. This test allowed validating the start-up process and correct initialization of all DDU components.
- Test case 3. Backup power supply and UPS. In this test, all actions aimed at validating the correct operation of the redundancy in the power supply of the system were carried out. Likewise, tests were carried out to verify the operation of the prototype using only the UPS as power supply.
- Test case 4. HMI functionalities. This test allowed verifying the deployment of the human machine interface, according to the required

functionalities for each case. It was validated that the different views and tabs of the HMI allowed visualizing the information coming from the sensors. Fig. 3 shows a screenshot of the summary tab of the HMI developed by COTECMAR for the DDU prototype.

Fig. 2. Functional DDU prototype - laboratory test configuration.

- Test case 5. NDPs (Navigation Data Producers) data integration. This test allowed validating that the simulated information coming from the different onboard systems and sensors, which act as navigation data producers or providers, was effectively being managed in the processing units and could be displayed in the DDU's HMI, for its subsequent sending to the consuming systems. To run this test, the use of the NemaStudio signal simulator and the program developed by COTECMAR to reproduce sensor frames taken from onboard the units were required.
- Test case 6. NDCs (Navigation Data Consumers) data integration. In this section the information coming from the NDPs was validated to be available in the outputs that would be connected to the navigation data consumers. Additionally, with the execution of this test, the redundancy of the DDU data processing units was validated, based on the interruption of data sending by one of the processors and verification that the NDCs were receiving the relevant data. To perform this test the use again the Nema Studio simulator, the frame player developed by COTECMAR and an application for serial data capture running on a computer simulating a navigation data receiver were necessary.
- Test case 7. Integration of own and

Fig. 3. DDU HMI Summary tab [9].

Fig. 4. NemaStudio simulator - example of GPS configuration[10].

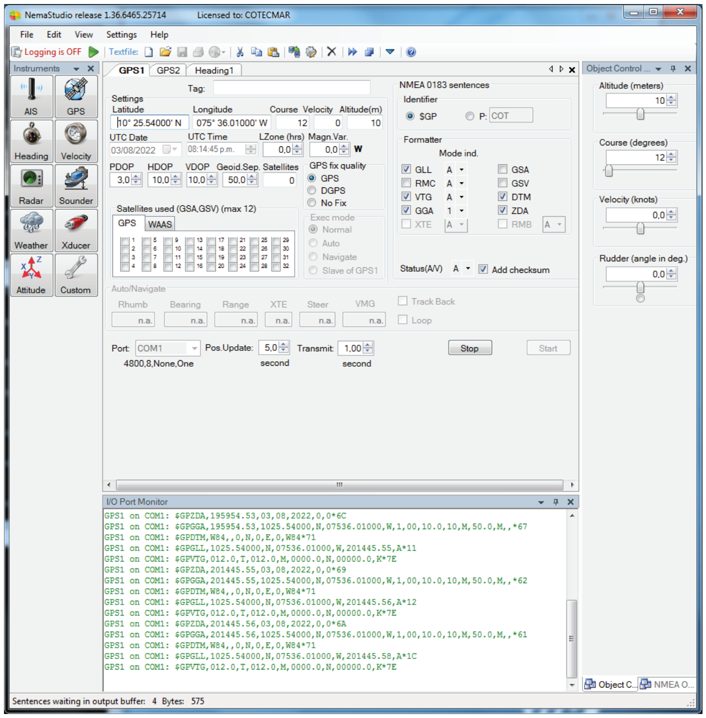
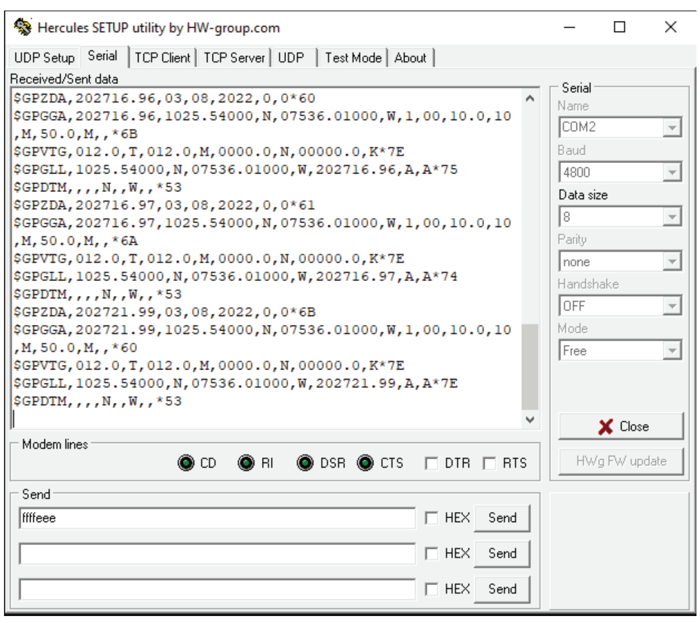


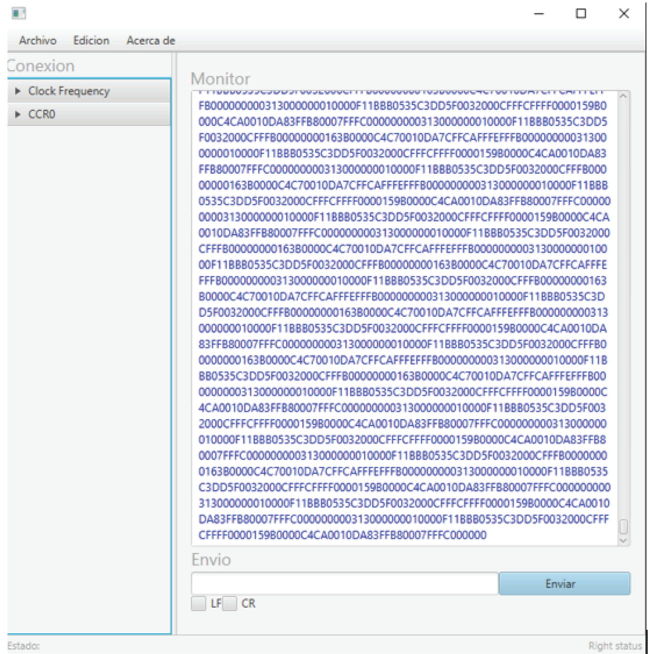
Fig. 5. Serial data reading application [11].



stabilization data. This test allowed validating the frames that are processed and generated by the DDU prototype, from the information coming from the sensors and NDP systems, which is required by the ship's weapon system.

For the execution of this test, in addition to having the applications described in test case 6, it was necessary to have the FASTCOM HDLC frame application (developed by COTECMAR) in a computer.

Fig. 6. Byte stream - HDLC frame monitor [12].



The execution of the described test cases had a duration of one (01) day, under controlled temperature and environment conditions, as follows:

- Ambient temperature: below 25°C.
- Available power supplies: main 115VAC/50Hz; backup (simulated) 24VDC.
- NDPs simulator: Gyrocompass, GPS, Echo sounder, Weather station, AIS, logger.
- There are two (02) data outputs for each simulated input sensor.

It is important to highlight that the test protocol described was 100% completed, successfully fulfilling the objective of the research project. The validation of the results was carried out by personnel of the Colombian Navy, belonging to one of the Almirante Padilla class frigates.

Considering the results obtained in the laboratory tests, the Colombian Navy requested to execute tests of the DDU prototype on board a Frigate. This implied making some adjustments to the hardware and software modules of the system, to adapt them to the operational environment on board; this process lasted approximately four (04) months. In general terms, the ARC personnel of the Frigate expressed their acceptance towards the prototype developed thanks to the successful integration of the navigation and combat systems on board. Although there were some novelties and opportunities for improvement during the test period, all of them were addressed and solved in a timely manner by COTECMAR.

Fig. 7 shows the prototype DDU developed by COTECMAR installed (provisionally) on board a frigate for testing in a real operating environment.

Main challenges

The development process of the DDU prototype involved the analysis and solution of some situations that materialized and that, in some way, became challenges that had to be solved and managed to achieve the successful execution of the project.

Tables 1 and 2 describe some of the situations identified, classifying them according to whether they applied to hardware or software modules.

Table 1. Challenges - hardware modules.

Factor or Requirement	Description Situation	Solution
Card redundancy for onboard digital and analog signals.	The cards used in the on-board DDU were a custom solution made by a manufacturer. They are not available commercially.	Detailed study and analysis of the logic required for the solution and subsequent design/development of the cards to guarantee signal redundancy.
High-speed signals	It was necessary to integrate high speed signals (250,000bps) and the tools required to acquire this information on board were not available for the laboratory testing process of the prototype.	Identification, acquisition, and configuration of specific hardware to be able to extract the information required for the execution of tests. It is important to highlight that the acquisition of this hardware had a high cost associated with it.
Pinout documentation	Basic technical documentation. There was insufficient detail on the physical integration of some of the existing DDU modules. This delayed the onboard signal integration process.	Field analysis of the signals and internal pinouts of cards, to build a detailed documentation of the developed prototype.
Laboratory test signals	The *synchro* signal in analog format could not be validated in the laboratory, due to the lack of 115VAC 400Hz signal generators.	This signal was tested on board a Colombian Navy frigate.
On-board test execution times	Long power-on (and stabilization) times were required for sensors and on-board systems, which altered the planned work schedule for test execution.	Schedule management, based on adjustments to the test schedule and joint work with the ship's personnel for effective coordination prior to the execution of the tests.
Procurement of components	Delays in the logistical process of acquiring hardware components required for project execution, as an indirect consequence of the pandemic. Prolonged manufacturing lead times for specialized components.	Schedule management. Contact with suppliers to agree on dates adjusted to the requirements and execution of parallel design and information gathering activities to avoid delays in the project master schedule.
Signal multiplexing	During the execution of tests on board the Frigate, problems were being generated in the transmission of input information to the DDU prototype developed by COTECMAR.	A detailed case analysis was performed. The input signals (from onboard sensors/systems) were separated and grouped according to their data rates.

Fig. 7. Functional DDU prototype-testing aboard a frigate.

Conclusions

The application of the existing knowledge and capabilities in the R&D department of COTECMAR, allowed the development of a functional prototype of a Data Distribution Unit - DDU, adjusted to the requirements of the Almirante Padilla class frigates of the Colombian Navy. In this sense, the functional validation of the development was done both in the laboratory and in a real operational environment (on board a frigate), obtaining successful results in both cases.

Likewise, this project allowed the appropriation of new knowledge and capabilities related to systems and sensors integration, especially regarding the management of onboard analog signals and their respective digitalization.

Likewise, based on the technical challenges and difficulties encountered during the prototype

Table 2. Challenges - software modules.

Factor or Requirement	Description Situation	Solution
Synchro documentation	There was no documentation describing the exact data that made up the output frame of this signal.	Field tests were carried out to analytically identify the necessary treatment of the data to generate the signal.
Missile system data documentation	Poorly detailed documentation of the processing of data going to the SS missile system.	Field tests were carried out to analytically identify the necessary treatment of the data to generate the signal.
HMI design	An HMI design was required that could group and represent the data of interest to the DDU operator, considering ergonomics and information prioritization criteria, which would also allow monitoring the information managed by the DDU in real time.	Several preliminary HMI designs were made and socialized at worktables with operators of the existing DDU in the ARC units, to have adequate feedback for the selection. Additionally, adjustments were made to the form (color, font sizes, decimal display, etc.) of the HMI during the prototype testing phases.
HMI development components	Once the graphic design of the HMI was selected, we worked on a version based on a tool that had a high RAM memory consumption, which caused the application to crash.	Identification and selection of components that would make a good treatment of RAM consumption and that would not imply the reduction of interface display capabilities.

development process, the following conclusions or lessons learned are generated, as follows:

- Around 30% of the problems that arose, both in hardware and software, were due to basic or outdated technical documentation, which meant that the technical personnel working on the project had to increase their dedication to field data collection and analysis activities to fill the information gaps.
- It is important to validate the designs with the end user or operator prior to the implementation phase of the projects. In this case, the validation of the HMI design with the onboard operators allowed to adjust and direct the interface development efforts in a timely manner, so that it would be functional and intuitive.
- The proper management of the schedule of a project of this nature, as well as the timely identification and mitigation of the risks detected, allow the efficient completion of objectives. In this case, we tried to parallelize hardware/software design and development activities with the logistic delivery times of the components required for the implementation of the prototype. This allowed mitigating delays in the project's macro schedule.

Recomendations

- Assign sufficient time to the process of selection and analysis of hardware component characteristics, so that the materials and equipment to be acquired fully meet the expected requirements.
- Ensure that the required components and tools are available to perform the laboratory validation tests of the advances.
- Continuously train the technical personnel involved in the execution of this type of projects, with a view to enhancing system and sensor integration capabilities.
- Maintain a continuous feedback process with the client or end user, to identify new requirements and guide future work.

Acknowledgments

The authors would like to thank the crews of the frigates of the Colombian Navy for their support in the development and testing process of this project, as well as the personnel of the Weapons and Electronics Department of BNL01 for their support in the design and validation process of the prototype.

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