Integration of PLM, MES and ERP Systems to Optimize the Engineering, Production and Business

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Abstract. In the era of Industry 4.0, the key factor for the success of a company is the cooperation among its different departments in order to share knowledge and information, thus optimizing time and cost. Three core IT systems are usually present in companies: Product Lifecycle Management (PLM), Manufacturing Execution system (MES) and Enterprise Resource Planning (ERP). PLM manages product and process design information, MES monitors and controls the execution of manufacturing process on the shop-floor, and ERP tracks business resources and the status of business commitments. This paper describes the integration process to optimize the engineering, production, business and management activities in a manufacturing company that operates according to the One-of-a-Kind Production (OKP). It explains the architecture of such integration as well as the methodology applied for the customization of the PLM, MES and ERP systems available in the company. Moreover, the paper highlights the specific solutions developed to integrate the data management of the different systems as well as the IoT technology supporting the data communication.

Keywords: PLM, ERP, MES, REST API

1 Introduction

Most of the large-scale enterprises relay on small and medium-sized enterprises (SMEs) for their products and services. SMEs play a vital role for the growth of industries and the economy of a country [1,2]. Nowadays demand for customized products has been increasing. In addition to customization, customers also expect the products to be delivered in a short time and approximately same cost as mass-produced product with a relative high quality. This market trend requires manufacturing companies to be able to produce customized products rapidly and cheaply with a required quality level. Customization strategies can be particularly observed in companies whose manufacturing processes are dedicated to manufacture the customized products, as considered to be unique product, by performing customer-order driven engineering known as "one-of-a-kind production", OKP [3,4].

Being most involved in the production of prototypes, OKP companies is of great importance for the collaboration among all the departments and the sharing of knowledge among the personnel. OKP decision making depends on the past learning experiences based on the similar products and processes which enable the designers and operators to adapt and/or modify the manufacturing process to improve the manufacturing efficiency. According to [1], the main strategy in achieving OKP system is the application of flexible automation and information technologies. The three core IT systems usually present in companies are Product Lifecycle Management (PLM), Manufacturing Execution system (MES) and Enterprise Resource Planning (ERP). PLM is a systematic and controlled method for managing and developing industrial manufacturing products and related information. PLM software offers management and control of the product process and the order-delivery process, the control of the product related data throughout the product life cycle, from the initial idea to the scarp yard [5]. MES is an IT tool that enables information exchange between the organizational level of a company and the control systems for the shop-floor, usually consisting in several, different, very customized software applications [6]. ERP is an enterprise-wide information system that integrates and controls all the business processes in the entire organization. It is an industry-driven concept and systems and it is universally accepted by business and organizational industries as a practical solution to achieve an integrated enterprise information system solution. ERP systems track business resources (e.g., cash, raw materials, production capacity) and the status of business commitments (e.g., orders, purchase orders, and payroll). It facilitates information flow between all business functions and manages connections to outside stakeholders.

One of the pillars of Industry 4.0 is the integration among data coming from different systems. The machines of a manufacturing plant are starting to be connected, following the Industrial Internet of Things (IIoT) paradigm. Currently, the usage of IoT is limited to analyze shop floor behavior by monitoring the environment parameters [7]. However, the most significant challenge is to integrate core IT management systems, to combine the end to end process from the manufacturer to the customer with new advanced business models. This paper proposes a model to integrate the core IT systems with the help of IoT technology to perform the end to end process seamlessly in at most real time.

While there is no particularly extensive literature on this subject, production is concentrated in the last few years. It is clear from this literature that the business strategy of a manufacturing company needs the data that are stored in the PLM, ERP and MES [14]. The MES functions and the MES-PLM data transferring is standardized by the ISA95-IEC62264 [15], and the data from the PLM to MES are classified in CAD model, plans, BOM, manufacturing process, work instructions and machine setup, while the flow from MES to PLM is represented by a report in which the production monitoring activity is summarized. The benefits of such integration are clear in the world of research and are also becoming clear among the industrial players who, however, for example in Italy, struggling to invest in the purchase of these three information systems, see the problem of their integration as a distant issue [16].

The rest of the paper is organized as follows: section 2 explains the functionalities of core IT systems in One-of-a-Kind Production. Section 3 explains the architecture of the Integration of PLM, MES, and ERP with the help of REST API protocol. Section 4 presents the application of the framework in the use case for an Italian automotive prototyping company. Finally, Section 5 draws conclusion and future work perspectives.

2 Functionalities of Core IT systems

The main issues associated with the OKP production are the frequent changes in the customer requirements and the inevitable changes occurring during the project management process that will cause delays in the final delivery [8]. For this reason, it is important to have a way of formally defining the work distribution among the different departments and allow them to communicate to manage the changes occurring during the project. Before defining the architecture of integration of three core IT systems, it is important to know the general functionalities of them which are also commonly seen in OKP. As PLM, MES and ERP are three core IT systems within a company, each of them has its own functionalities which help to flow the data seamlessly.

PLM is a design-level computing solution that looks for implementing an information management strategy generated during the life cycle of a product [9]. PLM is more than a computer system or technology, it is a concept, a strategy, that relies on technology to be applied and whose objective is to control and lead the life cycle of a product. The most important functionality of PLM is to manage the data related to the Product design and Process design. Furthermore, Process planning is another key functionality of PLM. Process planning has been defined as ‘‘the subsystem responsible for the conversion of design data to work instruction’’ [10]. A more specific definition of process planning is given as, ‘‘The function within a manufacturing facility that establishes the processes and process parameters to be used as well as those machines capable of performing these processes in order to convert a piece-part from its initial form to a final form which is predetermined on a detailed engineering drawing’’ [11]. To support the design of process plan, the following functionalities are also used:

- *Project management* is a tool that allows the project manager to control the scope and time of a project. The assignees are given the responsibility for specific activities in the project.
- *Parts and BOM management*, *Parts* are the basic item of any BOM management application, and can be one of the following classification types: Component, Assembly, Material, or Software. A part can be bought, or made in-house. It can have alternates and substitutes. It can have a Bill of Materials (BOM) associated with it, a list of manufacturers (AML) approved for making this part, a list of vendors (AVL) approved for purchasing this part, a list of documents (such as drawings or specs) associated with the part
- *Change Management Processes,* is a process by which any required changes to parts or documents are initiated, designed, reviewed and implemented. There are three basic items in Change management i.e., problem report (PR), enterprise change request (ECR) and enterprise change order (ECO).

- *Requirements Management,* is a tool which captures, trace and validate all the requirements throughout the development process
- *Quality Management,* is a tool encompasses of quality planning and quality systems. Quality planning will cover proactive side of quality i.e., the areas that involve design and/or process planning, risk analysis and risk mitigation. Quality Systems will cover the reactive side of Quality i.e., the areas that involve Issue Identification, Containment and Analysis and Corrective/Preventive Actions (CAPA).

MES system must identify the optimal sequence planning considering the constraints of the process, such as the time for setup and processing, and the capacity of the workstations, considering the requirements and the necessities given by the organizational level. MES doesn’t have only a single function but it has different ones that support, guide and track each of the primary production activities [12]. Functions of MES in OKP are:

- *Operational Scheduling*: It provides sequencing based on priorities, attributes, recipes associated with specific production unit of an operation.
- *Resource allocation and status*: It is a detailed history of resources and ensures that equipment is properly set up for processing and provides status in real time.
- *Product Tracking*: Monitoring the progress of units, batches or lots of output to create a full history of the product.
- *Performance Analysis*: It provides up-to-the-minute reporting of actual manufacturing operations results as well as comparison to history and expected result.
- *Quality Management:* It’s a real-time analysis of measurements collected from manufacturing to ensure correct product quality control and identifies problem. It recommends action to correct the problem, correlating the symptom, actions and results to determine the cause.

ERP system includes sales and marketing, finance and accounting, purchasing, storage, distribution, human resources and quality control functions [13]. The main functions of ERP in OKP are:

- *Manufacturing*: It provide tools for planning and scheduling, budgeting, forecasting, procurement and materials management.
- *Accounting:* It support accounts receivable, accounts payable and general ledger functions to manage the finances.
- *Customer Relationship Management:* It helps businesses track campaigns, nurture leads and maintain client information.
- *Inventory Management:* It exchanges data with manufacturing, distribution, sales and customer records. This gives greater visibility of the supply chain and help users to predict issues, such as late delivery due to low inventory levels, with greater accuracy.
- *Distribution:* It involves the processes that get a business’s product from the warehouse to its final destination. It manages functions like purchasing, order fulfilment, order tracking and customer support.

3 Architecture of Integration of Core IT systems

Integration of PLM, MES and ERP systems will give the full control over a product from the Customer order to the delivery of a product. It's an end-to-end process where data will flow seamlessly across different departments within the company, thus breaking the walls between the different functional areas in a company. The proposed Architecture for the integration of PLM, MES and ERP consists of a central Intelligence system called Knowledge Base System (KBS). KBS consists of a database in addition to the individual databases of each system. It is a structured central database in which the IT systems can transfer and withdraw the necessary information. It's a bi-directional dataflow between the IT systems and the KBS as shown in figure 1.

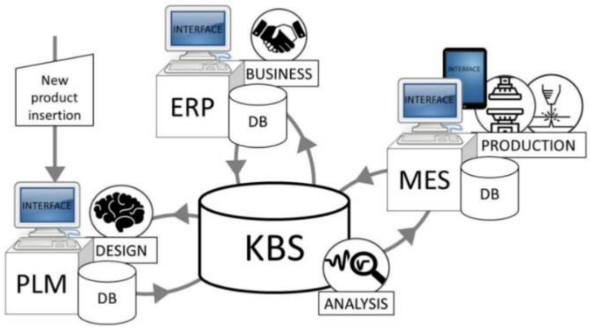

Fig. 1. Conceptual architecture of the knowledge base system

The proposed architecture will allow to collect all the information related to the new component in the KBS system, which helps to perform analysis on a product data. This analysis of product data helps in finding the patterns of different products of a same family, which will reduce the time for the product and process design and able to monitor the performance in the production line. To design such architecture, we have to observe the functional framework in one-of-a-kind production and the data flows among the PLM, MES and ERP.

3.1 Functional Framework in OKP

The generic functional framework in one-of-a-kind production is shown in figure 2. The functional framework figure explains that when a new shop order arrives from a customer, ERP as a system will consider and accept the shop order and send the shop order information to PLM to check with the similar Product history thus to interpret the product definition. At this point, KBS as a system plays a key role by providing best possible solution to PLM with similar product history, thus reducing the time in product planning phase. It's a collaborative process of PLM and ERP. Once the product is defined, PLM as a system design the product and processes by comparing with similar product history and share the information with ERP and MES. MES as a system give the command to the shop floor to build a prototype and check for any design modifications. If prototype meet all the constraints of Customer requirements, then MES instruct ERP for the resources allocation as per the demand. ERP instructs the PLM to provide bill of materials (BOM) information and it's a collaborative process of PLM and ERP. Once everything is setup, production process will start and the final product will be controlled by ERP system for the delivery to the customer. KBS as a system gives continuous feedback to the MES for any performance improvement in production line.

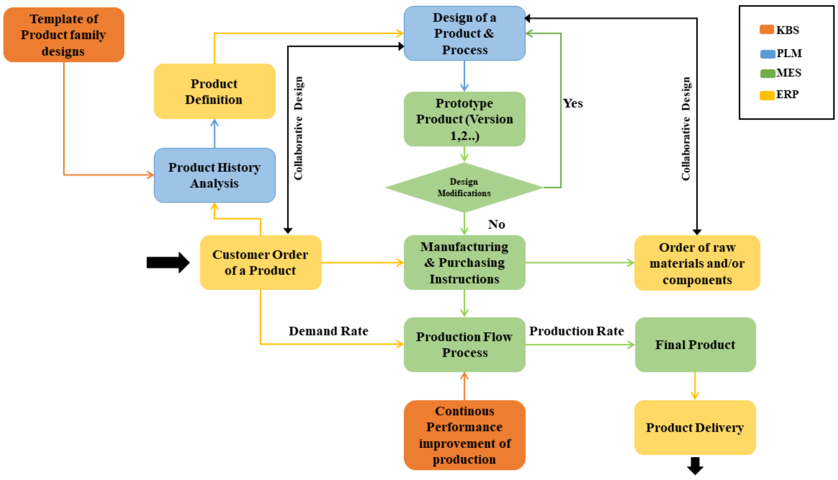

Fig. 2. Functional Framework in One-of-a-kind Production

As KBS database is a Structural database, it gives full freedom to communicate among the systems. Entity relationship diagram as shown in figure 3 explains the data flow among PLM, MES and ERP systems through KBS. When a New shop order arrives from a customer for a specific product, ERP system generate product specifications and store data in the entity called Product. Product Model(s) entity, which is a PLM item, generate one or more models for this product and each model consists of one or more parts (BOM). Manufacturing Process Plan is a PLM entity that defines the parameters of a production cycle for a product model and the corresponding entity called Manufacturing Operations defines the kind of operation, required resources and machines. It shares the relationship with list of operations entity which contains predefined operation details. On the other hand, MES entities called Production Request and Production Planning, help to define the production cycle and can be divided into one or more secondary orders. Production Request contains the data of a production order and Production Planning consists of data to manage the programming of operations of an individual cycle relative to a particular order. One of the key entity of the MES is Production Status because it contains information about the progress of the production. This entity evaluates the data entries to the Physical machine entity. Each one of the Physical Machine entity can have associated at most one Production Status. The Check

Start Output entity is linked to the Check Start Machine, which imposes certain controls to monitor before using a machine. Final product entity provides information about the status of a set of by-products and/or final products. This entity evaluates the statements saved in Production Status at time intervals, obtainingresult as the status of the articles declared: good, scrap or re-cycle. Final delivery entity, which is a ERP item, stores the data of final products labeled as good and delivered to the customer.

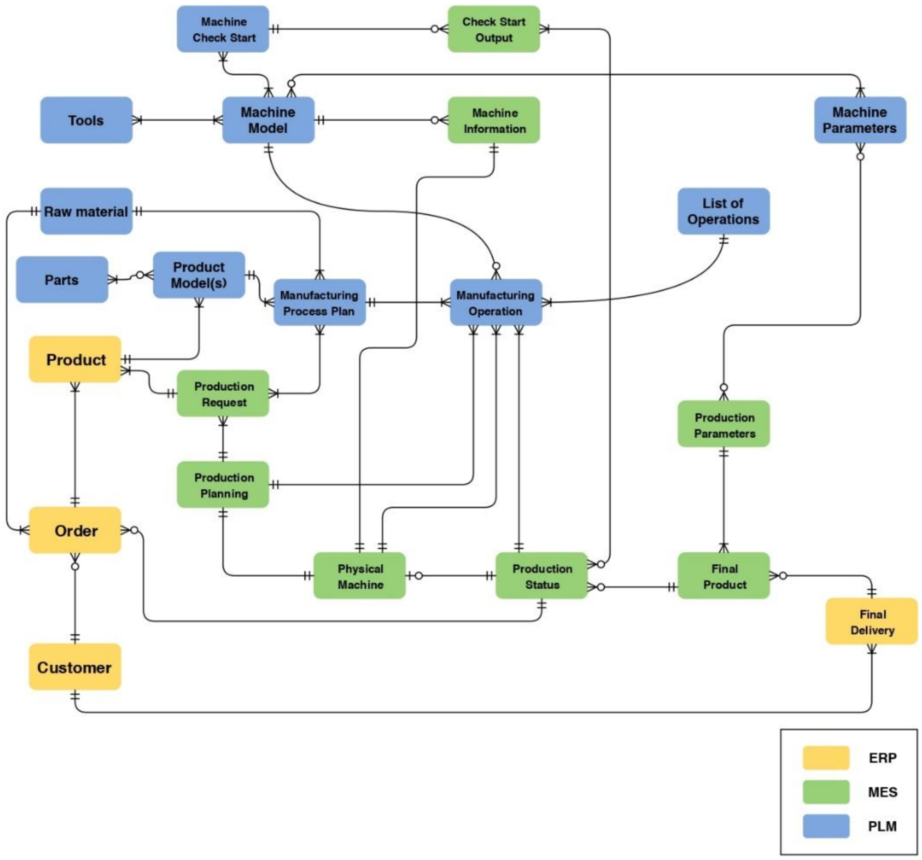

Fig. 3. Entity Relationship Diagram in KBS DB

3.2 Connectivity

In ground reality, Connectivity is crucial to implement the dataflow among PLM, MES, ERP and KBS. IoT is many things but at the end it's all about connectivity. In 21st century, Application program interface (API) changed the whole concept of connectivity. Currently REST and MQTT API's are predominantly in use. REST (REpresentational State Transfer) is designed as request/response that communicates over HTTP and MQTT (Message Queuing Telemetry Transport) is designed as publish/subscribe that communicates over TCP/IP sockets or WebSockets. MQTT is designed to be a fast and lightweight messaging protocol, and as a result, faster and more efficient than HTTP but MQTT needs a client implementation which is very rare than HTTP client implementation. PLM, MES and ERP are available in the market as an individual software's, so implementation of integration architecture via REST is the best possible choice for now. In REST, requests are made to an application URI and will obtain a response with a payload formatted in HTML, XML, JSON, or some other format. When HTTP is used, most common operations available are GET, HEAD, POST, PUT, PATCH, DELETE, CONNECT, OPTIONS and TRACE. Each application has a specific URL associated with it, that datum can be accessed depending on the syntax of the URL and represented in variety of ways. Each application's REST schema defines the types and specific points of data that can be requested. For example, the PLM schema includes Machine Model, Raw Materials, and so on as a points of data and includes a set of rules about how the request URL must be written in order to access the data. As REST API is a request/response model, we can set the repeat mode to an entity based-on time frame for the request/response depending on the priority. For example, Machine model or Machine Check start entities in PLM are static data to store in KBS which requires less priority compare to Manufacturing Process Plan or Manufacturing Operations.

4 Use Case

Case Study will help researchers to investigate on real world problems and to find solutions for the future progress. This research work will help SME's who follow One-of-a-kind production to integrate the systems in the company for the better efficiency.

4.1 Overview of a Company

The research study was conducted in an Italian company in automotive sector that is dedicated to the design and modifications of mathematical models and fundamentally to the construction of models and prototypes for automobiles. Its main function is to manufacture and assembly of sheet metal and aluminum components for prototypes and small series of automobiles and other road vehicles. The key success factor of this company is producing products which undergo complex manufacturing process in a short time. The company is a tier 2 supplier for global automotive manufacturers. The profile of the company is well suited for One-of-a-kind Production which follows producing customized products as per the customer requirements in a short time.

4.2 Industrial Processes in the Company

Industrial process begins with the new order by a customer who provides CAD Model of a product. The technical department of the company will analyze the CAD model and design the dies, Manufacturing processes and the required material. In the meantime, CAD office will validate the CAD model through simulations. If the Simulations doesn't show any critical issues in the model, it will send to CAM office in order to find the tool paths of milling machines for die construction. In order to accelerate the process and make less mistakes, the company also develop a Styrofoam model as a prototype which meets the requirements. This model will serve as a guide for the next stages. Once the dies are constructed, the metal sheets which are going to use to produce the body part are sent to laser office for trimming with 2D laser machines to obtain exact body outline. Then it will be taken to the sheet metal forming area where it undergoes press operation to acquire the requested shape. The resulting piece will send back to laser office where 3D laser machines cut the metal sheet according to specific laser paths obtaining the final piece. Depending on the complexity of the product, there might be additional operations of pressing and 3D laser cuttings to obtain the perfect finished product as per the customer requirements.

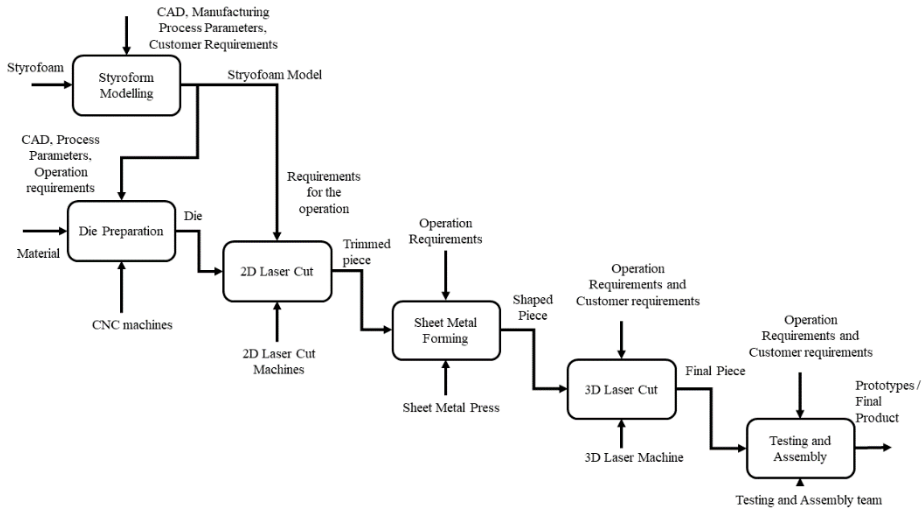

Fig. 4. Industrial Process in the company

4.3 Critical Issues in the Company

The production processes performed by the company is extremely variable and difficult: it is difficult to forecast the production trend, problems and misconceptions prevent the plant from having a linear production. The production of prototypes makes the industrial process much more complex compare to the series production. On the other hand, the production of prototypes is characterized by an extremely variable production rate and with high material waste, despite the great experience of the specialized employees. The problems that the company is facing are the type of production (prototype-making) that causes great difficulties in sequencing and scheduling of orders. Another critical issue commonly occurs in the company is the boundaries between departments. For example, in the design phase, role of a designer will end with the design approved by the responsible manager and the designer will not get any feedback on possible problems caused by the design during production. In the same way, shop floor operators will not receive the results of the simulations done by the CAD office that theoretically indicates the critical issues of the product. The lack of information flow in both directions leads to a lack of continuous learning. Another problem facing by the company is the absence of digital data collection of production systems i.e., no information is collected about the exact number of defectives or material waste. The only relevant data available in the company is the number of pieces produced at the end of the shift. Furthermore, no information is collected regarding the critical issues faced by the operators during the shift which causes dependencies on the experienced professionals of the company. The lack of a structured Knowledge Base System results in production problems and delays when such experienced employees are absent. Another issue commonly seen in OKP is to deal the situation when there are frequent changes in the customer requirements. The proposed architecture solved such problems since the different systems are inter-connected at all the levels and the time to change will be less compare to traditional ways. For example, when the ERP system receives the request for customer change requirements, it asks Manufacturing process plan designer in PLM and Production Manager in MES for the feasibility of customer changes. If it's feasible, changes in the design of product and manufacturing process will be done with a label of new version and the flow of work will be followed as shown in the **Fig. 2**.

4.4 Implementation of Integrated Architecture

The proposed architecture is an open source data acquisition system able to collect data from multiple applications and provide easy accessibility to such data. Therefore, it is very important to choose software's and the best technology which can give full freedom to the application engineer to create or modify the items and relationship with other items according to the integrated architecture. For this reason, the prototyping system has been developed with the following software's: Aras Innovator is an open source PLM software which gives freedom to customize the PLM platform according to the company needs; JPIANO is an MES application; eSOLVER is an ERP application, Node-RED is an open source application used as a platform to call REST API's, to process the data and push the data to KBS database; PostgreSQL is an open source database used as KBS database.

To implement the complex architecture described in Figure 3, we used Node-Red application to define the data flow from PLM database to KBS database, from ERP database to KBS database and vice versa. Since Aras PLM software provides 'uri' which is an URL address to a specific item, it gave possibility to extract the data using REST API. In the same way, we can also extract the data from ERP system. The database of MES system is incorporated with KBS database since the data of MES systems are very dynamic in nature. Figure 5 and figure 6 explain the data flow architecture among the systems. By exploiting the open source Node-Red packages, different nodes are used to serve the purpose. In the presented work, system gets the data via REST API 'GET' request, clean and structure the data as per the KBS database (PostgreSQL) format and sends to the KBS database via 'POST'/'UPDATE' request. As REST API is a request/response based, the system performs several iterations based on time interval and compares the acquired data with the existing data in KBS database. If the data is new, then it will ‘POST’ the data into the KBS database or, if a value of specific property of an entity is changed, it will perform ‘UPDATE’ operation. In the same way, another set of nodes will check for new data available in the KBS and perform ‘POST’/’UPDATE’ operation on the corresponding uri in the application database.

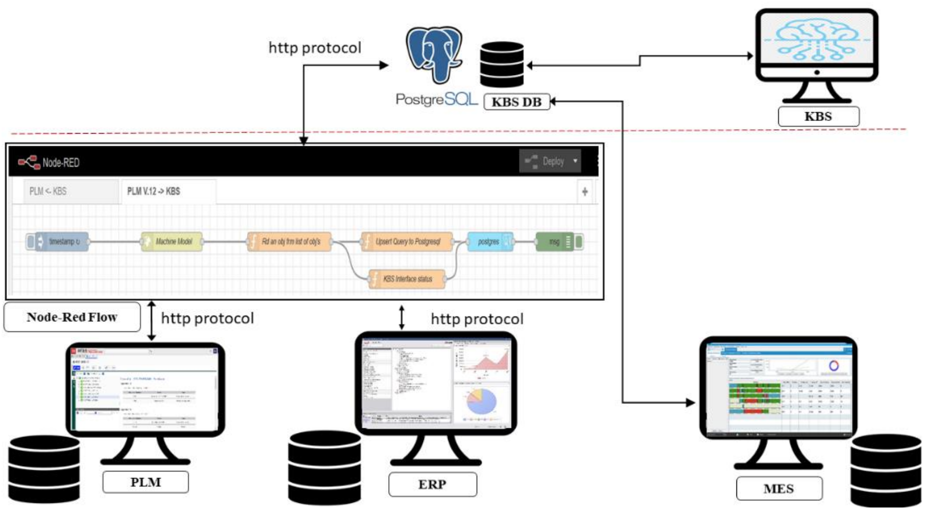

Fig. 5. Data flow architecture among the systems

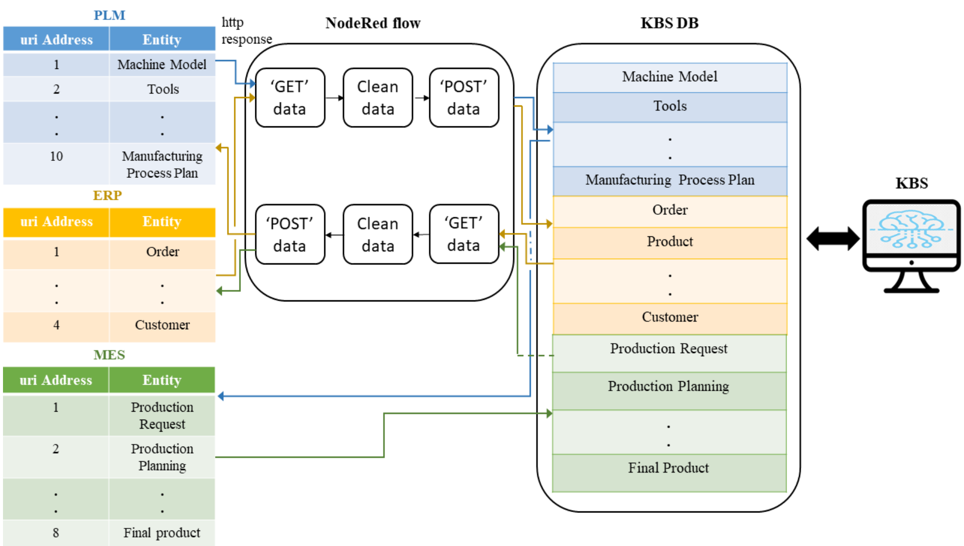

Fig. 6. Detail data flow architecture

5 Conclusion and Future Works

The objective of this paper is to propose a framework to integrate design, production and business systems which helps in reducing the time and cost to produce the product, especially in the companies who follow OKP which usually leads to the inevitable changes occurs in various stages of production. The framework is also an end-to-end process where data will flow seamlessly across different departments within the company, thus breaking the walls between the different functional areas. The system presented in this paper is a Knowledge base system which collects and integrates PLM, MES and ERP data, thus helps to find the uncertainties that occur during the design or production phase. The presented system is installed in the company and it's in a testing phase, which are performing by company design team, operators and other workers.

Our most promising future works will be generating the key performance indicators of various degrees and the application of various Machine Learning techniques to analyze the KBS data which helps in finding the patterns of different products of a same family, which will further reduce the time for the product and process design and able to monitor the performance in the production line.

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