COBEM 2021 26th International Congress of Mechanical Engineering
ABCM Associação Brasileira de Engenharia e Ciências Mecânicas
November 22-26, 2021, Virtual Congress, Brazil

COB-2021-0137
I4.0 COMPONENTS BASED ON SOFTWARE AND DOCUMENTS, AND A METHOD PROPOSED FOR UPDATING ERP MODULES FOR THE CONTEXT OF INDUSTRY 4.0

Felipe Ramos Braidotti
Fabrício Junqueira
Paulo Eigi Miyagi
Universidade de São Paulo, Escola Politécnica, Departamento de Engenharia Mecatrônica e de Sistemas Mecânicos
{braidottifelipe, fabri, pemiyagi}@usp.br

Abstract. *The 4th industrial revolution (**Industry 4.0**[1]) involves the revision of production systems to achieve a higher level of efficiency in decision making. The production system must be based on a system architecture specific to the environment of **Industry 4.0** and, in this sense, the most known proposal is **RAMI 4.0** (Reference Architecture Model for **Industry 4.0**). Associated with **RAMI 4.0**, there is the concept of **I4.0 Component**. As a mechatronic system, it consists of a real asset, for example a machine or product, and a digital part, called **AAS** (Asset Administration Shell), which has a detailed functional description of its use. However, the concept of assets is broader than just machines and physical products: documents and software are also considered assets in this context. Therefore, this work aims to evaluate and propose a way to approach software and documents as assets of **Industry 4.0** for the implementation of a productive system based on **RAMI 4.0**. This paper adopts a qualitative and exploratory approach for application, which procedures derived from bibliographic review, and feedback of case studies. The result of this paper is to stablish how to treat software and documents as assets and how they are related to their **AAS**. To demonstrate the developed solution, the materials management module of ERP systems (Enterprise Resource Planning) was used as an example of application.*

Keywords: *Industry 4.0, RAMI 4.0, Enterprise Resource Planning (ERP), mechatronic system.*

1. INTRODUCTION

The ***Industry 4.0***, known as the fourth industrial revolution, has autonomous factories as its main concept, which involves greater versatility of production processes and factories flexibility (Brettel et al., 2016).

This versatility comes from demands associated with many elements: products, machines, processes, etc. Within the ***Industry 4.0***, there is a branch named "smart factory" that involves all factory sectors that are interconnected. All components of a determined sector, as well as the sectors themselves, communicate between each other to optimize the decision making processes (Tandur et al., 2017). This strategy, associated with data and sector integration, has the purpose to anticipate eventual problems of each sector and the effects on the productive process. In a pre-***Industry 4.0*** scenario, this information exchange is made through an ERP (Enterprise Resource Planning) system by most of the companies (Krajewski et al., 2009).

An ERP system is used to achieve the complete information management of all company's sectors. This system is composed of modules that represent these sectors and can be contracted separately by the company (Oliveira et al., 2010). It is based on the MRP I (Material Requirement Planning) and MRP II (Manufacturing Resource Planning) systems and extents it's concepts to all areas of the company, resulting a "holistic approach for planning all the company's resources (people, equipment, financial, inventory, etc.) needed to fulfill the market demands" (Haddara and Elragal, 2015).

In turn, MRP I and MRP II were developed exploring the concept of BOM (Bill of Materials) and MPS (Master Production Schedule). The BOM is a list that comprises raw materials, subassemblies, subcomponents, parts, and the quantities of each one, required to build or manufacture the unity of a "Finished Product". For each "Finished Product", a MPS is created with the specification regarding quantity and delivery times based on a foreseen demand (Drexl and Kimms, 2013) and details how much final items will be produced according to specific time intervals based on clients' orders received in the same timeframe (Krajewski and Ritzman, 2004). Besides the MPS and BOM information, the MRP I utilizes the information about the current status of material inventory (Heisig, 2002), allowing it to follow the stock level and the replacement needs of components (Krajewski and Ritzman, 2004).

The MRP II is considered as a two-stage production, purchase, and delivery tool (Shehab et al., 2004). First stage: elaboration of manufacturing plans aligned to the capacity of the available and required resources (machines, labor, items, routes, and bottlenecks); second stage: combination of the manufacturing schedule, the required capabilities, and the data of the product's structure to plan the manufacturing delivery according to deadlines. It is considered as a software tool

[1] All terms related to the ***Industry 4.0*** concepts will be written in bold italic.

working as an integrator among all enterprise departments (known as "commercial units", and the plant developed to ensure that materials and other resources are available in time for production. Its operation is triggered by an order originated from a customer within the company's commercial department and ends with the production of the items described in such order (Drexl and Kimms, 2013).

In this way, inspired by MRP I and MRP II systems, the ERP modules were developed to cover all management areas of a company (Bytniewski et al., 2020) to facilitate the information flow through the supply chain processes. They can gather formatted data for future applications (Shehab et al., 2004), and with the module integration, every of them are able to access a unified database to send or receive information (Oliveira et al., 2010), as shown in Figure 1.

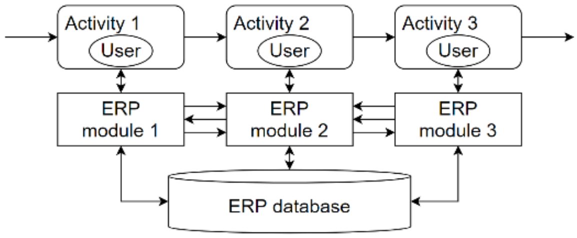

Figure 1. Flow through the ERP's modules, users, and database access

ERP systems have innumerous advantages which act in favor of its implementation. The decrease in setup time, maintenance coordination with production, and the physical display optimization are some of them, in addition to providing near real-time information to aid in decision making (Zezulka et al., 2016). In order to illustrate how software and documents can be considered as assets in the ***Industry 4.0***, and knowing the importance of ERP systems to medium and large companies, this work intend to present an approach to the ERP as an ***Industry 4.0*** asset, as well as its modules, since they can be contracted separately.

Therefore, in Chapter 2 the main concepts related to ***Industry 4.0*** relevant to this work are presented. In Chapter 3, a method proposed to migrate ERP modules to the ***Industry 4.0*** context is explained. In Chapter 4 an example of application of the method is presented, and in Chapter 5 there are final considerations of the work.

2. CONCEPTS OF THE INDUSTRY 4.0 RELATED TO THIS WORK

In this section, the main concepts of the ***Industry 4.0*** that can address the ERP implementation as an ***Industry 4.0*** asset are shown. It is dedicated to present ***RAMI4.0*** and ***I4.0 Components*** concepts.

2.1. RAMI4.0

RAMI4.0 is the most known architectural reference model for ***Industry 4.0***. It was originated by Germany's initiative regarding the industry development called ***Plattform Industrie 4.0***, which counts on the government, industry, and universities collaboration. The reference model (***RAMI4.0***) is represented by 3 axes (see Figure 2): (i) "Hierarchy Levels"; (ii) "Life Cycle Value Stream", and (iii) "Layers" (Pisching et al., 2018).

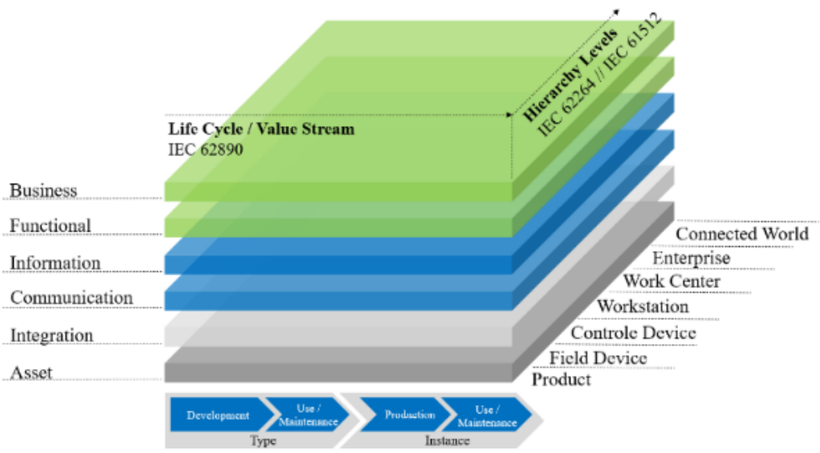

Figure 2. Representation of ***RAMI4.0*** axes

The ***Layers axis*** is related to the mapping of information and its distribution among the various sectors of a company. Here are the tools for data management, prediction of communication behavior, assets processes, etc. (Wang et al., 2017).

The shop-floor information and all its sectors are utilized in the company's transactions among those sectors (***Communication layer***) or between clients and suppliers (***Functional layer***). The focus of this work is on this axis, therefore, the other ones will not be addressed here. However, information regarding them can be found, for example, in (Pisching et al., 2018).

The ***"Asset layer"*** is responsible for the reality representation. It has objects such as machines, sensors, software, and documents, as well as people, ideas and patents (Pisching et al., 2018; Zezulka et al., 2016), control devices, workstations, products and more (Mourtzis et al., 2019). All assets are connected to the virtual world through the ***"Integration layer"*** (Adolphs et al., 2015) with the utilization of technologies as QR Codes, RFID tags, etc., which address the single identification of each asset (Wang et al., 2017; Zezulka et al., 2016).

The ***"Communication layer"*** is intended to allow communication among different assets in the network (machines, computers, controllers, etc.) utilizing protocols, such as OPC-UA (Lee et al., 2015), for example. In the ***"Information layer"***, data are checked and transformed into new high-quality data (information, knowledge) (Adolphs et al., 2015; Pisching et al., 2018). In this layer are located the products, equipment, departments, and processes databases (Adolphs et al., 2015; Zezulka et al., 2016).

2.2. **The I4.0 Component**

A ***I4.0 Component*** is an entity composed by the asset and its digital part, the ***AAS*** (***Asset Administration Shell***), responsible for the storage and availability of data and information regarding the asset (Bayha et al., 2020), as illustrated in Figure 3. Thus, the digital part has the function to manage the properties and information of the asset, while the real part has to meet the demands of the productive process in the physical world (Adolphs et al., 2015).

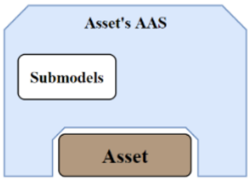

Figure 3. Generic representation of a ***I4.0 Component***

For this asset, or a group of assets represented by an ***AAS***, to be used in the ***Industry 4.0*** scenario, its description must be based on machine-readable properties (Bedenbender, et al., 2017a). The ***AAS*** can support engineering, offering the machine-processable data and making available information about asset functionality (Bayha et al., 2020). The machine-processable data description can be made, for example, using the eCl@ss standard, enabling the necessary semantic/ontological standardization (Bondza et al., 2018). However, the semantic/ontological study is not the focus of this work and more information about this subject can be found in the cited reference.

The ***AAS*** is the digital representation of the asset, therefore its structure is built from the ***"Integration layer"*** of ***RAMI4.0***. All characteristics about the asset are stored on it such as, technical description, properties, and functionalities. The ***AAS*** stores all this information in databases locally for each asset (in the ***"Information layer"***) using several ***submodels***. Each ***submodel*** must represent the detailed description and aspect of the asset in a standard way. The functions that are to be described in each ***submodel*** of the ***AAS*** are based on relevant properties specifically determined for that asset (Bedenbender, et al., 2017b).

There are developments regarding the standardization of ***submodels***. Some are of general use for all assets such as those proposed by (Bedenbender et al., 2020) and (Bader et al., 2020). Their work is based respectively on modelling the ***submodels*** "Nameplate" and "Technical Data", both for industrial equipment. Others are dependent on the sector of the economy and must be agreed between companies in each sector. In this context, one of the additional contributions of this work, presented in chapter 4, is the proposal of options for ***submodels*** which can be used for stock management of products and its dependent demand, considering the relevant properties for this purpose.

3. MIGRATION OF AN ERP MODULE TO THE INDUSTRY 4.0

Each ERP system module has important functions to address the company's operations, and the use of the functions of each one of them should be made in a standardized way. Because the migration is based on an existing system which are to be seen in the context of ***Industry 4.0***, a methodology was established (according to the cycle in Figure 4) to evaluate the actual ERP system module scenario and facilitate the understanding of the migration, so there are no information conflicts during the system operation. The steps used in this methodology are described in the sequence.

Step 1. Analysis of the current system

First, the analysis of the module and its functions is made to understand which elements participate on its digital interactions and how the information are managed inside the module. In the following, the relevant elements that participate in the transactions are identified and modeled as ***I4.0 Components***.

Step 2. *I4.0 Component* definition

In this step, the ***I4.0 Component*** are defined based on the assets that will be studied and which ***AAS***'s they must have within their lifecycle. Some assets, because they have more than one ***AAS***, represent more than one ***I4.0 Component***. The difference is in the nature of the properties related to that asset and the process steps where the information is used.

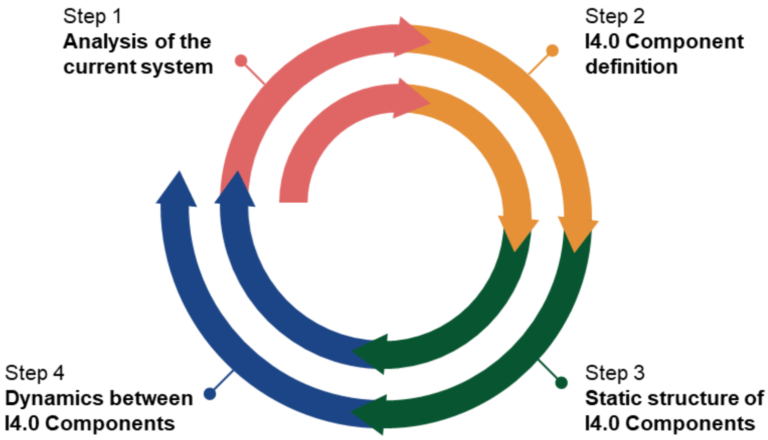

Figure 4. Process for migration applied to ERP modules in the ***Industry 4.0*** context

Step 3. Static structure of *I4.0 Components*

In the following, the ***submodels*** of the ***I4.0 Component*** are derived. Each ***submodel*** must follow the guidelines of the asset's lifecycle and which property and properties collections are relevant to the ***I4.0 Component*** relationships.

Step 4. Dynamics between *I4.0 Components*

Finally, ***I4.0 Components*** must communicate among them to establish an autonomous production environment. This communication is made through the ***"Communication layer"***. The objective of this steps is to describe which information will be transferred from one ***I4.0 Component*** to another always with the orchestration of the ERP module used in the case. Neither the structure of the messages nor the technology part is covered in this paper.

4. Application Example for the "Material" ERP module

The following methodology application example is focused on the "Material" ERP module and its functions required for resource management. All the steps are followed with concrete application suggestions to explain how this ERP module can be treated as an Industry 4.0 asset.

4.1 **Step 1 – Analysis of the current system**

The inventory control was the first action taken by the company regarding the resource management policies. Thus, the "Materials" module is one of the most present in companies. It eases the control of stock levels and promotes techniques of replacement and options when choosing some materials (Madanhire and Mbohwa, 2016) (Shehab et al., 2004). Whenever a material is consumed or added to the inventory, the system needs to update its status. The manufacturing of any good depends on the purchase of materials related directly or indirectly to the manufacturing operations. This module, through its interface and tools, seeks to speed up the search for raw materials, as the process of negotiation and recognition of well-rated suppliers is eased (as well as the purchase operation itself) (Zezulka et al., 2016).

4.2 Step 2 – *I4.0 Component* definition

The ***I4.0 Components*** in this case hold important properties related to the stock policies and inventory control. Those properties are used in MRP I calculations to assure that the client will be supported as soon as possible. Table 1 shows the ***I4.0 Components*** considered from the assets that are being studied and their respective ***AAS***'s.

Some assets have more than one ***AAS***, because the relevant properties for the production process dimensioning depend on each phase of the asset lifecycle. Knowing the ***I4.0 Components*** that are part of the case, their properties and functions are explained in the next paragraphs. Initially, the ***I4.0 "Materials" module*** is composed by the "Materials" module of the ERP system, in other words, it is the part of the software regarding the "Material" module itself and its ***AAS***. This ***I4.0 Component***'s ***AAS*** is used to describe its functions and specify communication protocols to other assets present in the ***I4.0 System***, working as a bridge to interact among other ***I4.0 Components*** and to make them interact among themselves. All MRP I logic is present in this ***I4.0 Component***. The values of stock levels are extracted from the others ***I4.0 Components***, although the dependent and independent demand calculations are made by the "Materials" module. When receiving the necessary values for the calculations, it computes the results and sends order requests to the responsible departments.

Table 1. List of ***I4.0 Components*** of this case

	AAS			
Asset	**Characteristics**	**Purchase Order**	**Production Order**	**Purchase Request**
Raw material (RM)	*I4.0 Raw material*	*I4.0 RM Purchase Order*	-	-
"Materials" module	*I4.0 "Materials" module*	-	-	-
Finished Product (FP)	*I4.0 Finished Product*	-	*I4.0 FP Production Order*	*I4.0 FP Purchase Request*
Intermediate Product (IP)	*I4.0 Intermediate Product*	*I4.0 IP Purchase Order*	*I4.0 IP Production Order*	-

4.3 Step 3 – Static structure of *I4.0 Components*

The Asset finished product has more than one ***AAS***, therefore it is involved with many different ***I4.0 Components*** in different moments of its lifecycle. This is because, for each stage of use, the group of properties can change. The ***I4.0 FP Purchase Request*** counts with the finished product for its physical part and with the ***AAS*** related to the purchase request of this product.

The properties of this ***I4.0 Component*** are present in the ***Submodel Request Information (SM-RI)***. Table 2 shows the description of the "ID", "Quantity" and "Delivery time" properties of the ***Submodel Request Information (SM-RI).***

Table 2. ***Submodel Request Information (SM-RI)*** properties

Properties	**Type**	**Description**
ID	*string*	Represents the asset's unique and individual identifier
Quantity	*int*	It is the real quantity presented in the purchase request
Delivery time	*string*	It is the maximum deadline determined between the client and the company, the customer agrees to receive the request without price and quantity adjustments

The ***I4.0 Finished Product*** is composed by the "finished product" and its ***Characteristics AAS*** which has ***submodels*** with specific properties that describe it as a ***I4.0 Component*** that will be used to scale the production process. The ***submodels*** present in this ***AAS*** are: (i) ***Stock Management (SM-SK)***; (ii) ***Production Organization (SM-PO)***; (iii) ***BOM (SM-BM)*** and (iv) ***Technical Data (SM-TD)***. Therefore, each ***submodel*** is detailed to its properties level. Starting with the ***Submodel Stock Management (SM-SK)***, Table 3 shows its properties and respective descriptions.

The next ***submodel*** of the ***I4.0 Finished Product*** is made by the collection (list) of materials that compose it, representing its BOM. Each material in this ***submodel*** has three properties: (i) ID; (ii) Quantity and (iii) Unity of measurement. Table 4 shows the properties that are part of the ***Submodel BOM (SM-BM)*** collections.

The third ***submodel*** of the ***Characteristics AAS*** regarding the finished product is the ***Submodel Production Organization (SM-PO)***. This ***submodel*** contains the collection of all operations from the productive process to manufacture the Finished Product. In other words, the operations are presented in the ***submodel*** in a sequential and logical order, knowing that each one of them contains its respective collection of materials, documents, and necessary capabilities of the assets so they can be fulfilled. Table 5 shows the collection that each operation contains.

Table 3. ***Submodel Stock Management (SM-SK)*** properties

Properties	Type	Description
Actual stock level	*int*	Represents the real stock level. It is the most dynamic value in the ***submodel***
Safety stock	*int*	It is the desired safety quantity to be in stock. Statistically, this quantity must guarantee that the stock doesn't run out
Maximum stock	*int*	It is the maximum value to have in stock after a scheduled purchase
Replacement level	*int*	It is the level in which the purchase must be done accordingly to the material's stock policies

The last ***submodel*** present in the finished product ***Characteristics AAS*** is the ***Submodel Technical Data (SM-TD)***. It is structured by the collection of different engineering disciplines technical data, looking forward the finished product application. This ***submodel*** is defined by the ***Plattform I4.0*** as "technical properties of the product" or "set of individual characteristics that describes the product and its technical properties". Therefore, there are project information, and the technical data used for finished product. This information is used by the company's engineering to develop equipment, improve processes, and so on.

Table 4. ***Submodel BOM (SM-BM)*** properties

Properties	Type	Description
ID	*string*	Represents the unique and individual identifier for the material. Through it, it is possible to stablish a relationship with this material ***AAS***
Quantity	*float*	It is the material quantity needed to manufacture the unity of the Asset Finished Product
Unity of measurement	*string*	It is the measurement unity used to measure the "Quantity"; for example: piece (PC), mass (kg, g, lb), volume (l, m^3, oz), and so on

Table 5. Collection of properties for each operation from the ***Submodel Production Organization (SM-PO)***

Collection	Description
Materials	Contains a list of the materials comprising the process operation. Each material has its own properties accordingly to their respective ***AAS***'s
Capabilities	Contains a relation of the necessary capabilities to fulfill the process operation. Each capability has its own properties accordingly to their respective ***AAS***'s
Products	Contains the list of product versions that are considered as this operation output. Each product has its own properties accordingly to their respective ***AAS***'s
Documentation	This collection has, for example, videos, photos and schematic drawings regarding the operation

Once the purchase request comes from a client, if the stock level of finished product cannot meet the demand, a production order must be launched. The production order is composed by many kinds of information about the asset and production processes of its digital part. Then, a ***Production Order AAS*** is introduced to store this information. As a result, the ***I4.0 FP Production Order*** is the ***I4.0 Component*** to address this issue. Its ***AAS*** comprises the following ***submodels***: (i) ***Resume (SM-RE)*** and (ii) ***Operations (SM-OP)***. In the sequence, the ***submodels*** belonging to this ***I4.0 Component*** are detailed in Table 6. Some properties comprised by the ***Submodel Resume (SM-RE)*** are references to other elements already shown.

The next ***submodel*** of the ***I4.0 FP Production Order*** refers to the productive processes steps that are needed to fulfill the related production order. The ***Submodel Operation (SM-OP)*** does not have its own properties, instead it has a collection of productive process's steps present in the ***Submodel Production Organization (SM-PO)*** of the ***I4.0 Finished Product***. This reference is made to ensure that there is no inconsistency in the information, no matter the process or stage of the asset's lifecycle. Accordingly, to Table 1, the intermediate product has, throughout its lifecycle, the ***AAS***'s related to its ***characteristics*** and ***Production Order*** have the same properties and collection as was shown for the finished product.

However, if the intermediate product is not internally manufactured, in other words, it is a purchased item, then the ***Characteristics AAS*** of this asset no longer possess the ***Submodel BOM (SM-BM)*** neither the ***Submodel Production Organization (SM-PO)***, once they are ***submodels*** that support the item production management, and now has the ***Submodel Purchase Information (SM-IC)***, which is composed by the collection of suppliers comprising the following properties for each one, as shown in Table 7: (i) Price; (ii) Shipping; (iii) Lead time; and (iv) Reputation.

Table 6. ***Submodel Resume (SM-RE)*** properties

Properties	Type	Description
Request reference	*string*	It stores de ID of the ***Purchase Request AAS*** responsible for the production order creation
Product reference	*string*	It stores de ID of the ***Characteristics AAS*** regarding the asset to be manufactured
Quantity	*int*	It is the sum over the quantity shown in ***Purchase Request AAS*** and the difference amount to meet the stock policies for the asset
Deadline	*string*	Receives the maximum deadline value to meet the client's requirements. This calculation is only made when the delivery times of dependent and independent demand are known
Batch	*string*	Stores the batch ID comprising this production order
Responsible people	-	Collection of responsible professionals for the production order with their respective positions and assignments

Table 7. ***Submodel Purchase Information (SM-IC)*** properties collection relative to the suppliers

Properties	Type	Description
Price	*float*	It is the product value in the supplier. It can be expressed in any commercial currency
Shipping	*float*	It is the shipping value that the supplier offers to delivery its product within the stablished lead time in contract
Lead time	*int*	Time between the purchase order confirmation and the material delivery, in days
Reputation	*float*	Value between 0 and 1 (0 to 100%) represents the supplier's reputation according to its price policies, quality, and lead time within the company

Besides, the ***Production Order AAS*** exists only for internally manufactured intermediate products. If this item is purchased to meet the production demand, then the ***AAS*** adopted to manage this new Asset is the ***Purchase Order AAS***, resulting in the ***I4.0 Component*** called ***I4.0 IP Purchase Order***. It has two ***submodels***, the ***Submodel Commercial (SM-CO)*** and the ***Submodel Delivery (SM-DY)***. The first comprises the following properties: (i) Quantity; and (ii) Price reference, as it can be seen in Table 8, and the second has the following properties: (i) Lead time reference; and (ii) Shipping method. Table 9 shows these properties, its types, and descriptions.

Table 8. ***Submodel Commercial (SM-CO)*** properties

Properties	Type	Description
Quantity	*int*	It is the asset's quantity to meet de internal manufacturing demands
Price reference	*float*	It stores the asset's price related to the selected supplier to deliver the purchase

Table 9. ***Submodel Delivery (SM-DY)*** properties

Properties	Type	Description
Lead time reference	*int*	It stores the asset's lead time related to the selected supplier to deliver the purchase
Shipping method	*string*	Represents the shipping method. For example: conventional, priority, express, etc.

The raw material is being considered as an asset that will always be purchased by the manufacturer. Therefore, it has the ***Characteristics AAS*** and ***Purchase Order AAS*** during its lifecycle. As they were already explained, the details of these ***AAS***'s will not be exposed. The only difference is that the asset is the raw material, thus the resulting ***I4.0 Components*** are: (i) ***I4.0 Raw material***; and (ii) ***I4.0 RM Purchase Order***.

With the presentation of raw material as an asset and its AAS's, the static structure of the "Materials" module is defined, and it is possible to study the interactions among the elements regarding it. In the sequence, the proposed dynamic structure for the "Materials" module utilization as an ***Industry 4.0*** Asset is presented.

4.4 Step 4 – Dynamics between I4.0 Components

In this section, the interactions among the ***I4.0 Components*** are shown to identify the information flow and how does the ***I4.0 "Material" module*** can manage the generation of production orders, purchase orders and product delivery supported by the defined ***AAS***'s. The following sequence of steps refers to Figure 5.

The purchase request of a finished product is received by the ***I4.0 "Material" module*** and must be processed regarding the manufacture product quantity (I). Once this information arrives at this ***I4.0 Component***, the process of interaction among other assets within the company is started. The first internal step is querying the ***Submodel Stock Management (SM-SK)*** of the ***I4.0 Finished Product*** (II). In this moment, the information of the stock levels is collected and, if the manufacturing is necessary, a production order (for finished products) is launched (III) while the quantity to be manufactured is registered in the ***I4.0 "Material" module***.

In the next step, this ***I4.0 Component*** query the ***Submodel BOM (SM-BM)*** of the finished product (IV) to identify which items (dependent demand) compose it because it will be necessary to query their respective ***Submodel Stock Management (SM-SK)*** in a similar way as done to the finished product (V).

If the needed quantities of each dependent demand listed in the finished product's BOM, multiplied by the quantity described in the production order (of finished products) results in a reduction of these items stock levels below the replacement level, so there is a demand for the manufacturing or purchase of these items, accordingly to their stock policies. This dynamic is presented in a sequence of steps in Figure 6. There are two possible scenarios for an intermediate product: (i) internal manufacturing or (ii) purchase. Regarding the raw material, the deal considered is only purchase. If the intermediate product is internally manufactured, a production order is generated for it, resulting in the ***I4.0 IP Production Order*** (VI.1) and must be analyzed in a manner analogous to the procedure determined for the finished product.

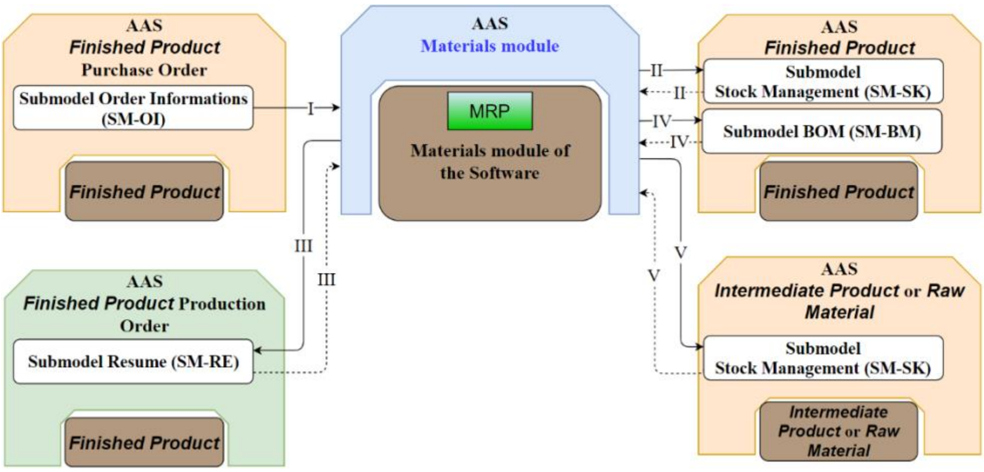

Figure 5. Interaction between ***I4.0 Components*** and finished product's production order generation

However, if the intermediate product needs to be purchased, as happens with the raw material, so a purchase order is created to this item (VI.2). In this case, the ***I4.0 "Material" module*** must receive the information from the ***Submodel Purchase Information (SM-PI)*** to send them to the ***Submodel Commercial (SM-CO)*** and ***Submodel Delivery (SM-DY)*** inside the ***Purchase Order AAS***.

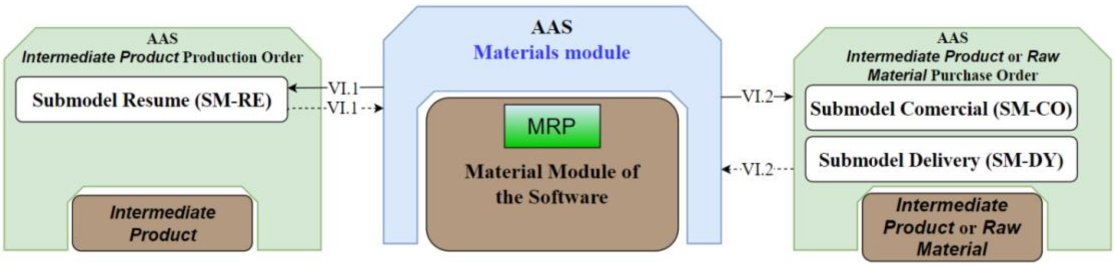

Figure 6. Independent demand production and purchase order generation

5. FINAL CONSIDERATIONS AND CONCLUSIONS

The ***I4.0 Component*** applications usually correlate a physical part, the asset, with a digital part, the ***AAS***. However, information, documents, and even software have been seen as assets in ***Industry 4.0***. In this sense, this paper addressed the "Material" management module from and ERP system, as well as the products information (raw material, intermediate, and finished products), as ***Industry 4.0*** assets and introduced a methodology to model them as ***I4.0 Components***.

When introducing the ***AAS*** and their application in the assets, making them ***I4.0 Components***, it is possible to notice how the information organization gets facilitated, as in the ***I4.0 FP Production Order*** case, which is represented by its ***Production Order AAS*** in the digital part and by the final product in the physical part.

Special attention should be paid to the “Material” module because it is a digital asset, as already mentioned. In other words, the ***I4.0 Components*** generated with it have two digital parts: the asset and the ***AAS***. In this case, the ***AAS***, in addition to present the asset for the ***I4.0 System***, works as a bridge for the module interact with other ***I4.0 Components*** in a standardized way. Thus, the ***I4.0 “Material” module***, through its ***AAS***, should consult the information of any ***I4.0 Component*** through the ***RAMI4.0 “Communication layer”*** and proceed with the autonomous demand management.

As the “Material” module (as well as other ERP modules) is very known by the companies, to make the ***I4.0 Component*** construction process more didactic, a method to migrate information from the current model to ***Industry 4.0*** scenario was introduced. As an additional result, this paper proposed some important ***submodels*** that contain properties related to the stock management of items, aiming to contribute towards the standardization of ***submodels*** related to ERP systems.

After the material definition and their requested quantities to deliver a production which fulfills a purchase request from an outside client, the company must select the assets that will manipulate and process these materials to execute the productive process steps described in the ***Production Order AAS***. This selection in the “smart factory” scenario must be done in an autonomous way by the assets with an ERP module implemented.

Future developments of this work include the improvement of the method presented in this paper, with its application to other ERP modules, such as production and maintenance.

6. ACKNOWLEDGEMENTS

The authors thank the support of the *Coordenação de Aperfeiçoamento de Pessoal de Nível Superior* (CAPES), the *Conselho Nacional de Desenvolvimento Científico e Tecnológico* (CNPq) and the *Fundação de Amparo à Pesquisa do Estado de São Paulo* (FAPESP).

7. REFERENCES

Adolphs, P., Epple, U., Bedenbender, H., Dirzus, D., Ehlich, M., Hankel, M., Heidel, R., Hoffmeister, M., Huhle, H., Kärcher, B., Koziolek, H., Pichler, R., Pollmeier, S., Schewe, F., Walter, A., Waser, B., & Wollsclaeger, M. (2015). Status report. In *VDI* (Vol. 28, Issue 4). https://doi.org/10.1353/cal.2006.0031

Bader, S., Bedenbender, H., Billmann, M., Bondza, A., Boss, B., Erler, S., Garrels, K., Hadlich, T., Hankel, M., Hillermeier, O., Hoffmeister, M., Kiele-Dunsche, M., Neidig, J., Orzelski, A., Pollmeier, S., Rauscher, B., Rieder, W., & Stein, S. (2020). *Submodel Templates of the Asset Administration Shell Generic Frame for Technical Data for Industrial Equipment in Manufacturing: Vol. 1.1*.

Bayha, A., Bock, J., Boss, B., Diedrich, C., & Malakuti, S. (2020). *Describing Capabilities of Industrie 4.0 Components*.

Bedenbender, H., Bentkus, A., Epple, U., Hadlich, T., Hankel, M., Heidel, R., Hillermeier, O., Hoffmeister, M., & Huhle, H. (2017). *Relationships between I4.0 Components – Composite Components and Smart Production*. 56.

Bedenbender, H., Billmann, M., Bondza, A., Boss, B., Dogan, A., Fay, A., Garrels, K., Hadlich, T., Hankel, M., Heidel, R., Hillermeier, O., Hoffmeister, M., Jochem, M., Neidig, J., Orzelski, A., Pollmeier, S., Schaber, V., Stein, S., Weber, I., … Zhang, Y. (2020). Submodel Templates of the Asset Administration Shell ZVEI Digital Nameplate. In *Plattform Industrie 4.0* (Vol. 1, Issue 1). https://www.plattform-i40.de/PI40/Redaktion/EN/Downloads/Publikation/Submodel_templates-Asset_Administration_Shell-digital_nameplate.html

Bedenbender, H., Billmann, M., Epple, U., Hadlich, T., Hankel, M., Heidel, R., Hillermeier, O., & Hoffmeister, M. (2017). *Examples of the Asset Administration Shell for Basic Part*. *April*. https://www.zvei.org/fileadmin/user_upload/Presse_und_Medien/Publikationen/2017/April/Asset_Administration_Shell/ZVEI_WP_Verwaltungschale_Englisch_Download_03.04.17.pdf

Bondza, A., Eck, C., Heidel, R., Reigl, M., & Wenzel, S. (2018). Toward Smart Manufacturing with Data and Semantics. In *eCl@ss, Classification and product description* (Issue February). https://www.eclass.eu/fileadmin/downloads/ecl-Whitepaper_2018_EN.pdf

Brettel, M., Klein, M., & Friederichsen, N. (2016). The Relevance of Manufacturing Flexibility in the Context of Industrie 4.0. *Procedia CIRP*, *41*, 105–110. https://doi.org/10.1016/j.procir.2015.12.047

Bytniewski, A., Matouk, K., Rot, A., Hernes, M., & Kozina, A. (2020). Towards Industry 4.0: Functional and Technological Basis for ERP 4.0 Systems. In *Studies in Computational Intelligence* (Vol. 887). https://doi.org/10.1007/978-3-030-40417-8_7

Drexl, A., & Kimms, A. (2013). Beyond the Manufacturing Resource Planning (MRP II). In A. Drexl & A. Kimms (Eds.), *Journal of Chemical Information and Modeling* (1st ed., Vol. 53, Issue 9). Springer Berlin Heidelberg.

Haddara, M., & Elragal, A. (2015). The Readiness of ERP Systems for the Factory of the Future. *Procedia Computer Science*, *64*, 721–728. https://doi.org/10.1016/j.procs.2015.08.598

Heisig, G. (2002). *Planning Stability in Material Requirements Planning Systems* (M. Beckmann & H. P. Künzi (eds.)). Springer Berlin Heidelberg. https://doi.org/1010079783642559280

Krajewski, L., & Ritzman, L. (2004). *Administração da Produção e Operações* (V. Rodrigues (ed.)). Pearson Prentice

Hall.
Krajewski, L., Ritzman, L., & Malhorta, M. (2009). *Administração de Produção e Operações* (Arlete Souza (ed.); 8th ed.). Pearson Prentice Hall.
Lee, J., Bagheri, B., & Kao, H. A. (2015). A Cyber-Physical Systems architecture for Industry 4.0-based manufacturing systems. *Manufacturing Letters*, *3*, 18–23. https://doi.org/10.1016/j.mfglet.2014.12.001
Madanhire, I., & Mbohwa, C. (2016). Enterprise Resource Planning (ERP) in Improving Operational Efficiency: Case Study. *Procedia CIRP*, *40*(2001), 225–229. https://doi.org/10.1016/j.procir.2016.01.108
Mourtzis, D., Gargallis, A., & Zogopoulos, V. (2019). Modelling of Customer Oriented Applications in Product Lifecycle using RAMI 4.0. *Procedia Manufacturing*, *28*, 31–36. https://doi.org/10.1016/j.promfg.2018.12.006
Oliveira, H., Carneiro, R., Oliveira, E., Santos, V., & Quintairos, P. (2010). *SISTEMAS ERP – Enterprise Resources Planning: Vantagens*, *Desvantagens e Aplicações*. 1–4.
Pisching, M. A., Pessoa, M. A. O., Junqueira, F., dos Santos Filho, D. J., & Miyagi, P. E. (2018). An architecture based on RAMI 4.0 to discover equipment to process operations required by products. *Computers and Industrial Engineering*, *125*(January), 574–591. https://doi.org/10.1016/j.cie.2017.12.029
Shehab, E. M., Sharp, M. W., Supramaniam, L., & Spedding, T. A. (2004). Enterprise resource planning: An integrative review. *Business Process Management Journal*, *10*(4), 359–386. https://doi.org/10.1108/14637150410548056
Tandur, D., Gandhi, M., Kour, H., & Gore, R. (2017). An IoT infrastructure solution for factories. *IEEE International Conference on Emerging Technologies and Factory Automation, ETFA*, 1–4. https://doi.org/10.1109/ETFA.2017.8247729
Wang, Y., Towara, T., & Anderl, R. (2017). Topological approach for mapping technologies in reference architectural model industrie 4.0 (RAMI 4.0). *Lecture Notes in Engineering and Computer Science*, *2*, 982–990.
Zezulka, F., Marcon, P., Vesely, I., & Sajdl, O. (2016). Industry 4.0 – An Introduction in the phenomenon. *IFAC-PapersOnLine*, *49*(25), 8–12. https://doi.org/10.1016/j.ifacol.2016.12.002

8. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.