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Proposal of a Reference Model in BPMN Notation for an MRP System

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Abstract *— Companies are progressively investing in practices aimed at improving the quality of management, with the main purpose of enabling them to operate competitively in the present market. For this, it is necessary to document the activities and information of the existing business processes in the organization, aiming at reducing time and cost in the elaboration of the particular model. In this context, the objective of this work is to develop a reference model of the Manufacturing Resource Planning (MRP) processes, an important module of production planning and control (PPC). The research methodology used in this work was divided into the following stages: study of MRP and business process modeling, definition of reference model processes, choice of methodology and process modeling tool, development of reference model and prototype of the software and, finally, analysis of results. The modeling notation used was the BPMN, since it is considered a standard language in the field of process modeling. The prototype was developed through the Delphi interface in order to apply the model to support the implementation of business management programs. As results, from a formal documentation, the model proved to be a useful mechanism in the understanding of the processes raised and appropriate in the support to the implantation of production management tools.*

Keywords — Reference Model. Production Planning and Control. Manufacturing Resource Planning. BPMN.

I. INTRODUCTION

Organizations are progressively investing in business quality practices such as: reengineering processes, adoption of an integrated management system (ERP), ISO certifications, lean production, costing by activities, among others. However, most of the high-investment and long-term investment actions, for example, in the adoption of ERP (BREMER; LENZA, 2000; CORREA; SPINOLA, 2015).

Quality management and process management units that are carried out, which are raised and documented Existing Business Processes in the organization.

However, a business process modeling activity is still not a common issue among organizations (THURER; FILHO, 2012), which is responsible for increasing the cost and time of implementation of the system or projects to improve the development of new models related to Business Processes (BREMER; LENZA, 2000). As a company already had a reference model, this activity would not be necessary. According to Scheer (2000), case studies using reference models can reduce the cost and pace of deployment of organizational projects by up to 30%.

In the business context, Business Processes are important for the expansion process, such as Brazil, where production activities are more pronounced than product development, and Production Planning and Control (PPC). This process is done by surveying demand, planning production, planning capacity, producing

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materials, scheduling production, etc. (FERNANDES; GODINHO FILHO, 2010; MUKHOPADHYAY, 2013).

The basic exercises of the PPC hierarchy, related to Material Planning, are the Manufacturing Resource Planning (MRP). According to Girotti et al. (2016), the MRP model determines the quantity and timing of the modules, components and raw materials needed to produce a given quantity of final products considering inventory levels and delivery times.

According to Thurer and Filho (2012), most companies, especially small and medium-sized companies, have a science that their PPC activities can be closed and that "processing time" and "work in progress" higher operating energy. However, the authors, as they simply do not know how to do this, are a vast majority of research and solutions for the PPC is focused on large and complex companies.

Therefore, it is important and growing attention, both the academic environment and not to undertake, there is no development of models that support any planning of entrepreneurial resources (CORREA; SPINOLA, 2015). However, these studies were designed to investigate PPC models and are mostly focused on industrial purposes and that address modules of specific production management activities.

In order to become companies, especially small and medium enterprises, in the development and implementation of business management actions, the present work aims to develop a reference model that addresses the related Business Processes as MRP activities.

In addition, this work also aims to develop a software prototype through the Delphi interface (Object-Pascal language), in order to apply the reference model to support the implementation of business management systems.

The article is organized as follows: a section 2 addresses a literature review on model reference and MRP; a section 3 presents the methodological procedures used in this study; a section 4 presents results obtained; and finally a section 5 presents as final endings.

II. LITERATURE REVIEW

2.1 Reference Model

Reference modeling is defined as the process of formally documenting a problematic domain in order to understand and communicate stakeholders (SIAU, 2004; SIAU; ROSSI, 2011).

The reference models, which can be developed in real situations or in theoretical studies, document the various aspects of a business process (BREMER; LENZA, 2000). According to Scheer (2000), one can distinguish between procedural models or standard software implementation, and business models such as models for production management and product development.

According Vernadat (1996), a reference model must contain a certain degree of generality and be customizable. Therefore, it should serve as a basis for discussion, a formal or semiformal suggestion for the elaboration of specific models, bringing information regarding the design of a business process. Keller and Teufel (1998) understand that reference models can be applied in cases of accumulated experience in a business type, and in business process solutions implemented and executed in business management software.

Vojislav and Leon (2000) propose that choosing the right reference models helps to minimize possible errors in the early stages of modeling and deploying management systems. This allows the design of a process or system to begin with the appropriate choice of requirements and also with the establishment of appropriate characteristics given by the reference model.

According to Bremer and Lenza (2000), the objective of the reference model is to provide the company with an initial solution for its Business Processes, so that, through this, the particular model of the company can be specified and detailed. According to Climent, Mula and Hernández (2009), reference models are useful in the description and graphical representation of the important aspects of a particular process, distinguishing, for example, people, departments and the connection between them. Additionally, Vergidis, Turner, and Tiwari (2008) models adequately portray and represent processes, emphasizing those aspects that need to be communicated and addressed.

Bolloju and Leung (2006) suggest that during the analysis phase of an information system development, the conceptual model can be used to capture and represent the development and deployment requirements of such technologies. For Scheer (2000), the use of reference models can reduce the cost and time of implementation of organizational projects, for example in the adoption of ERP.

In a review elaborated by Hernandez, Mula and Ferriols (2008), it was proposed that a reference model describe the social and physical aspects of the world in order to understand and communicate. In addition, it was also described that the reference model should go beyond the terms "specifications" and "requirements" and apply three linguistic concepts (syntax, semantics and pragmatics) to four aspects of modeling: language, domain, model and participants.

In summary, according to Vernadat (2003), the advantages of adopting reference models are to reduce time and cost in the development of the particular model; comparing the activities of the company with the

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activities proposed in the model, that is, best practices; and better support in deploying integrated enterprise management systems.

The model to be developed in this work will give greater emphasis to the information and activities that compose the PPC process, because its main objective is support in the implementation of organizational improvements, such as business management systems (Figure 1).

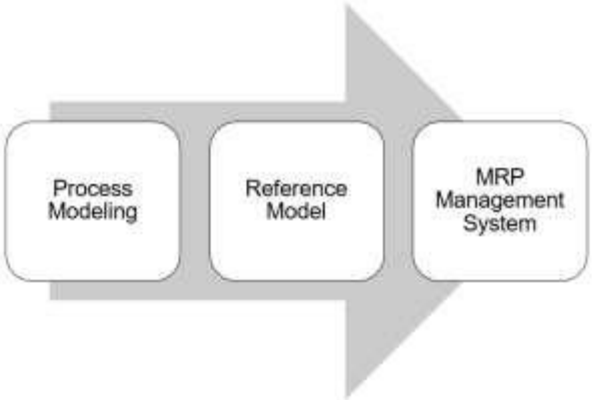

Fig. 1: Process of elaboration of the reference model

2.2 MATERIALS REQUIREMENTS PLANNING

A decision is made on the basis of the information available. Many of the material management decisions of a company are made with the help of the MRP (Materials Requirements Planning).

The MRP, created in the 1960s, is a logical system of calculation that converts demand forecasting into programming of the necessity of its components, being predominant present in PPC systems in manufacturing processes (MENDES, FILHO, 2017)

The MRP model determines the quantity and timing of the modules, components and raw materials needed to produce a given quantity of final products, as specified in the MPS, considering inventory levels and delivery times (GIROTTI et al. , 2016).

In addition, according to Favaretto (2012), MRP performs detailed production planning, which releases production orders and purchases the product components according to expected demand and available inventories. The fulfillment of delivery times and the production costs of the companies depend in part on the good result of this planning. For the author, the main information used in the decisions of this planning stage is related to the following variables: demand, inventory levels and spare times. If these variables are uncertain, the planning result may show errors.

Guerra, Schuster and Tondolo (2014) reiterate that through MRP, it is possible for companies to better manage and monitor inputs, raw materials, components, products under preparation and finished products. Due to the great complexity of some products (large number of items, components, parts and accessories), the PPC area frequently uses MRP, aiming at reducing inventories, obtaining greater predictability of receiving materials and inputs, reducing time of processing of the product, as well as fulfillment of the deadlines of delivery of the final product to the clients.

Therefore, the purpose of the MRP is to perform the material requirements planning activity computationally, thus enabling the determination of the priorities of the purchase and manufacturing orders. For Carvalho, Silva Filho & Fernandes (1998), the main objective of the MRP is to preset the raw materials (or supplies) according to the time (or factory capacity), which will be necessary to produce the order book of a organization.

MRP is based on requirements planning according to the Master Production Plan, which is prepared according to customer demand, Bill of Materials (BOM) (YENISEY, 2006), and quantities in inventories of the BOM items (NEELY; BYRNE, 1992). Figure 2 graphically shows the inputs required in the MRP systemand what outputs such a system provides.

According to Figure 2, MPS provides for MRP which products will be produced within the planning horizon for which the resource requirements will be calculated. The BOM provides the "parent" and "child" items to be produced according to the MPS, the gross demand for each item and the production and delivery lead time of the suppliers. Finally, the stock situation file provides the quantity in stock of each item to be subtracted from the gross need and found the need for material to be produced during the planning horizon adopted (YENISEY, 2006).

The MRP model is characterized as a "pushed" production system, which generates orders of production and purchase according to the master production program, material lists and stock levels. From the production and purchase lead times, the instants in which the orders are to be released are determined, applying a programming logic to "behind" (GIACON; MESQUITA, 2011).

Godinho Filho & Fernandes (2006), supported by Gaither & Frazier (2005), highlight the main benefits of MRP are: to improve customer service, with greater attention to deadlines and deliveries; reduce inventory investments; and improve the operational efficiency of the manufacturing organization.

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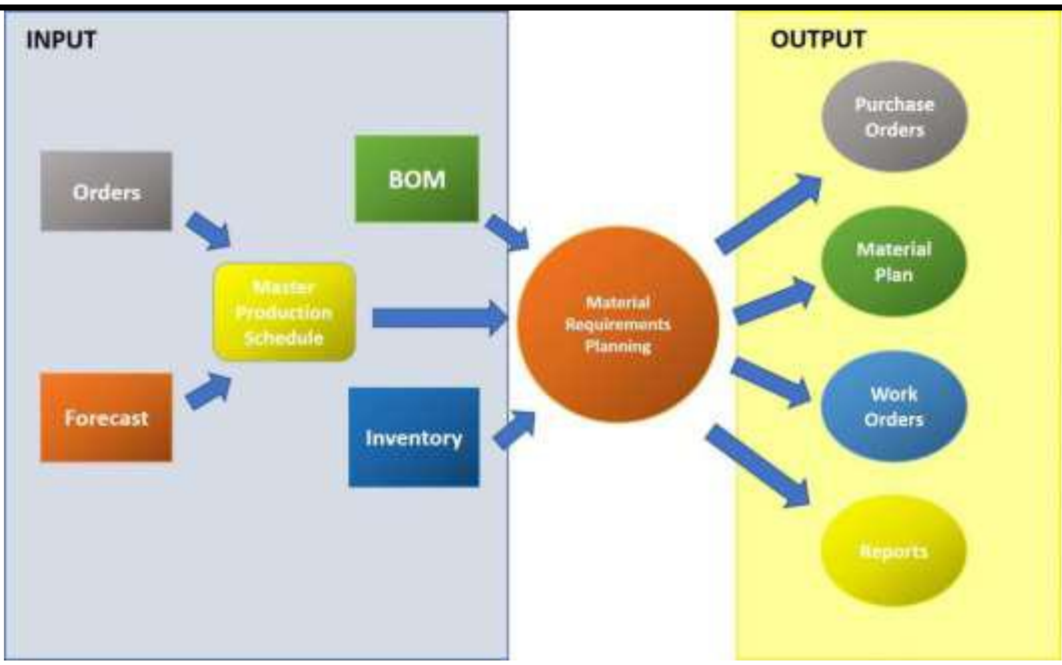

Fig. 2: Outline of MRP implementation

However, Sagbansua (2010) emphasizes that information accuracy plays a vital role in MRP as the benefits of this system depend heavily on the availability of the use of computers that will keep data up to date on the needs of a certain component of production. Errors in the inventory or bill of materials records would result in missing parts, oversupply of some products and lack of others, deviations from the production schedule, all of which cause poor results, such as poor customer service, inefficient use of resources and deliveries to customers. Therefore, companies planning to use this system must carefully evaluate the benefits and needs of MRP.

According to a survey by Jonsson & Mattsson (2006), 75% of manufacturing companies used MRP as the main material planning method. As noted by Ornek & Cengiz (2006), Pandey, Yenradee & Archariyapruek (2000) and Taal & Wortmann (1997), the relative simplicity of MRP systems makes them preferred by many approaches to mathematical programming.

For Milne, Mahapatra and Wang (2015), users understand MRP logic and develop a good understanding of the relationships between inputs and outputs of this system. For authors, this understanding allows users to identify which input data is in error and which needs to be improved for best results. Because MRP users understand these input/output relationships, they tend to be more confident in the results of production plans by MRP than the production plans issued by mathematical programs of unknown source codes.

An additional reason to use MRP is that many large corporations have licenses for software in which MRP modules are integrated with other corporate functions. Due to this integration and relative simplicity, MRP systems offer managerial flexibility that can be difficult to obtain in material planning systems based on mathematical programming (MILNE; MAHATMA; WANG, 2015).

Capacity Requirements Planning (CRP) aims to support the decisions of the detailed planning of production and materials, MRP (MUKHOPADHYAY, 2013). This planning, according to Corrêa et al. (2009), has as main objectives the anticipation of resource needs that require a few weeks to mobilize and also the generation of a detailed plan of purchases and production that is viable, through adjustments made in the original plan suggested by MRP, so that it can be released for execution by the factory.

At this level, it is not necessary that the calculation of capacity be fast, since assuming that the RCCP (Rough Cut Capacity Planning) was well done, there should not have been many problems to be analyzed, which must be solved by small adjustments in the orders of production. In addition, the MRP calculation itself is relatively time-consuming and does not, as a rule, allow for many simulations. The important thing is that the calculation is as accurate as possible, assuming, of course, the typical inaccuracies of the infinite capacity planning logic (CORRÊA; GIANESI; CAON, 2009).

The typical planning horizon is a few weeks, and the limit is given by the MPS (Master Production Schedule) horizon, which defines the maximum MRP horizon. Thus, the short-term capacity planning period is one week, such as RCCP (CORRÊA; GIANESI; CAON, 2009).

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III. RESEARCH METHODOLOGY

3.1 DEFINING THE SEARCH METHOD

The reference model was developed from theoretical studies. Thus, this research uses the procedures of bibliographic research, since it was developed from previous works such as dissertations, articles and books on the subject matter. In this way, the future work can be based on the conclusions presented in this article, and elaborate hypotheses aiming to deepen the study on the subject or related specific aspects.

On the other hand, this research can also be classified as experimental, since it is based on the creation of a reference model of a MRP system, modeled through software. Thus, with the objective of developing a reference model and exposing the way it was developed from the analysis of the activities involved in the processes, allow this work to be classified as a descriptive research.

3.2 SCOPE OF RESEARCH

The phase of process identification and hierarchization levels is considered the key step in process modeling, aiming to identify all existing Business Processes in a particular activity of an organization.

Figure 3 presents the model of the PPC Process hierarchy relating the planning of the capacity of its resources with the planning of the needs of its materials. The hierarchical decomposition of the PPC function starts from understanding the basic concepts related to material planning levels, namely: Sales & Operations Planning (S&OP) and Aggregate Planning (AP); Master Production Planning (MPS); Material Requirements Planning (MRP) and Production Scheduling (PS) (CORRÊA; CORRÊA, 2012; MUKHOPADHYAY, 2013). This work will be limited in the development of the MRP reference model and its respective capacity planning. The modules of the Production Planning and Control function related to Capacity Planning are Resource Requirements Planning (RRP), Rough Cut Capacity Planning (RCCP) and Capacity Requirements Planning (CRP).

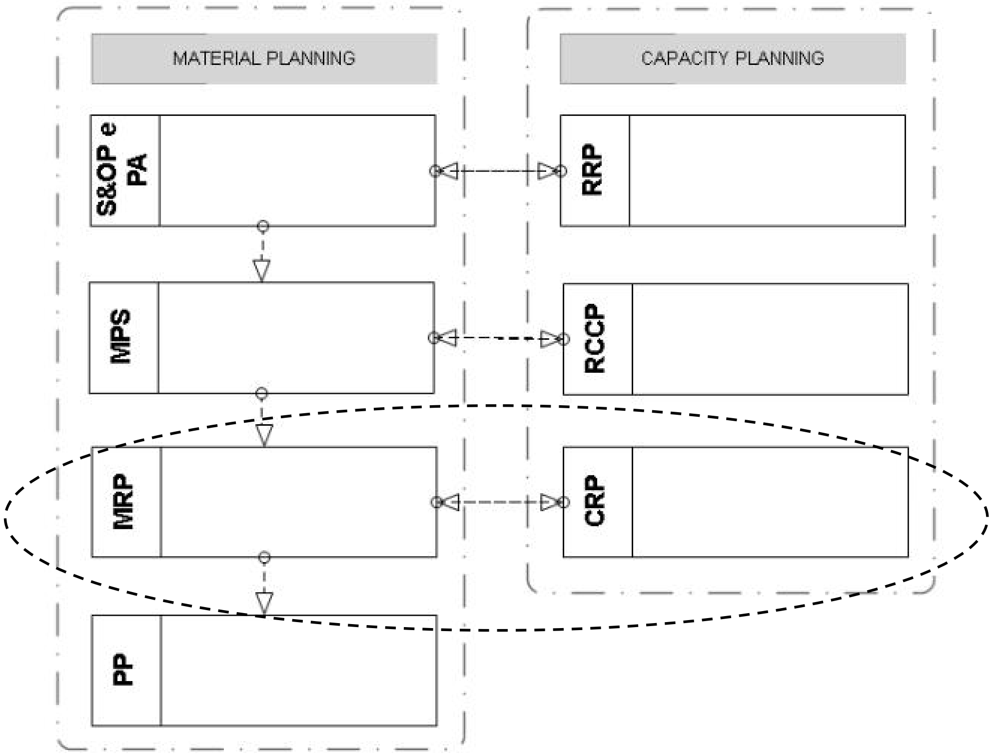

Fig. 3: Hierarchy of production planning and control

3.3 STAGES OF THE RESEARCH METHODOLOGY

The methodology used for the elaboration of this work was divided into eight sequential stages, as shown in Figure 4.

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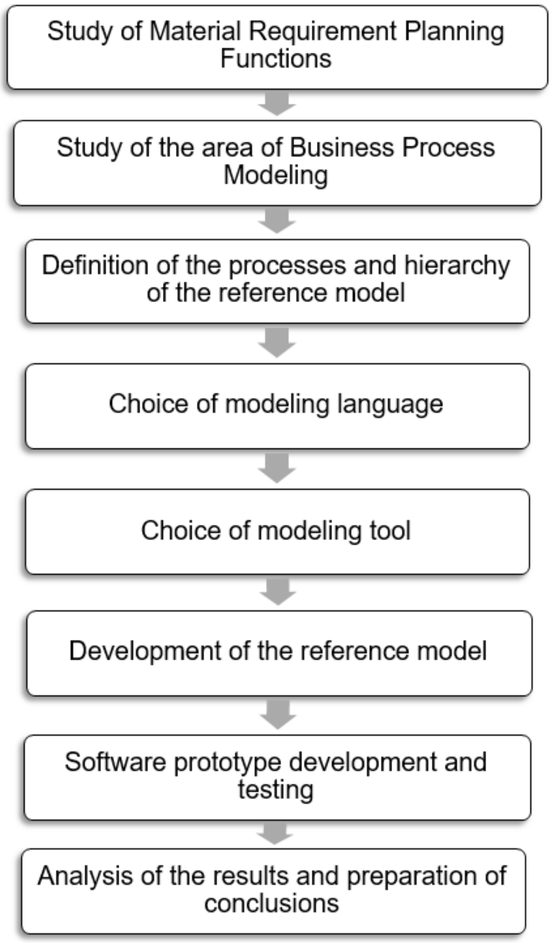

Fig. 4: Stages of the research methodology

- *Step I* - Study of Production Planning and Control Functions: In this stage, according to bibliographical references related to the topic of study, concepts, activities and information and functions of a typical production planning hierarchy were raised and studied;
- *Step II* - Study of the Business Process Modeling area: In the second stage, the concepts and languages regarding process modeling, as well as reference models, were studied and analyzed from the scientific literature;
- *Step III* - Definition of the processes and hierarchy of the reference model: In this third step, after the phases of the bibliographic review, the processes and hierarchy that will make up the reference model of a PPC system were defined;
- *Step IV* - Choice of the modeling language: In this fourth stage, the modeling language used for the development of the reference model was defined. The modeling notation selected was BPMN;
- *Step V* - Choice of the modeling tool: In this step, the modeling tool was defined, in order to provide facilities in the understanding and visualization of the model, that is, the full understanding of the functions of a system. The modeling tool selected was Bizagi Process Modeler version 3.1.0.011;
- *Step VI* - Development of the reference model: In this step, based on the language and defined modeling tools, the reference model of a PPC system was developed based on BPMN theory and notation;
- *Stage VII* - Development of application software and tests: In the seventh stage, once the reference model of the PPC system was elaborated, a software prototype was developed with the purpose of applying and validating the model, from the Delphi version interface 7.0, which used the Object-Pascal language;
- *Step VIII* - Analysis of the results obtained and conclusions drawn: In the last step, the results presented in the previous phases were analyzed and discussed, as well as the conclusions obtained and suggestions for future work

IV. RESULTS AND DISCUSSION

4.1 MRP MODELING

MRP, in short, is a logical calculation system that converts demand forecasting into requirements programming for its components. From the knowledge of all the components of a given product and the times of obtaining each of them, one can, based on the future vision of the needs, calculate how much and when to obtain of each item, so that there is no shortage or surplus in the supply of production needs.

The input and output information required to prepare the reference model of the MRP module are shown in Table 1.

Table 1: MRP information

Input	*Output*
Bill of Materials (BOM)	Gross material requirements
Short-term planning period	Projected Stocks of Materials
Gross demand for materials	Planned Receipts of Materials
Scheduled component receipts	Orders released from materials
Initial Stocks of Components	Material requirements plan
Levels of safety stocks of components	
Component batch sizes	
Batch sizes rules for components	

The activities related to this module of the MRP are presented, with their respective theoretical references, in Table 2.

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Table 2: Sequence of MRP activities

#	Activity	Theoretical Framework
1	Definition of BOMs for the final products from the production master plan.	Girotti et al. (2016), Corrêa & Corrêa (2012), Moreira (2008), Gaither & Frazier (2005) , Yenisey (2006) and Neely & Byrne (1992).
2	Definition of the short-term planning period.	Corrêa & Corrêa (2012).
3	Calculation of gross requirements.	Girotti et al. (2016), Corrêa & Corrêa (2012), Moreira (2008), Gaither & Frazier (2005) and Carvalho, Silva Filho & Fernandes (1998).
4	Calculation of projected inventories.	
5	Calculation of planned receipts.	
6	Release of planned orders.	Girotti et al. (2016), Favaretto (2012), Corrêa & Corrêa (2012) and Moreira (2008).
7	Verification of the need to analyze another component of the BOM.	Girotti et al. (2016), Corrêa & Corrêa (2012), Gaither & Frazier (2005), Yenisey (2006) and Neely & Byrne (1992).
8	Issue of the material requirement plan.	Corrêa & Corrêa (2012).
9	Review the material requirements plan if necessary.	

The reference model of the proposed Material Requirements Planning initially includes the definition of BOMs, a structured list of all components of the final product to be planned. Information about final products is taken from the MPS stage, which determines which products will be made and on which dates.

Next, the definition of the planning period (short term) is carried out, and this time period must come from the period that was established in the previous planning stage, that is, in the MPS.

For the calculation of gross requirements, it is necessary to extract information from the BOM regarding the structure of the components at each level of production, as well as the quantity required to be produced for each unit of production of the component (gross demand), according to the master plan of production of the final products. For each planned level of materials required for the production of the final product, information on the orders released from the lower level materials is required in order to calculate the required quantity (gross requirement).

After calculating the gross requirements, the projected inventories are calculated. For this, it is necessary to take into consideration, in addition to the gross requirements, inventories from the previous planning period to the current, scheduled receipts, if any, and also the level of security stock. If the current planning period has a production request to be made (planned receipts), according to the gross requirements, the projected inventory is recalculated.

For the calculation of the planned receipts, it must be verified if the inventory level meets the gross requirements of the planning period, always respecting the security stock level established in the previous step. If the level does not meet the needs, this value is calculated taking into consideration the lot size and lot size. At this stage, the establishment of MPS production levels takes into account information from the CRP regarding short-term productive capacity.

After setting the planned receipts, the planned order release is established according to the delivery time of each material and the assembly time of the planned final product.

Once the release of orders for a particular component has been defined, it is verified whether there is a need to analyze other BOM material, since, as already mentioned, the bill of materials has planning levels, so that quantities of materials (demand) are dependent on others.

After the completion of the planned order release of all items that make up the BOM of the final product, the material requirement plan is issued. In case of need, it is possible to carry out a review of this plan elaborated. After review, the consolidated MRP plan is issued.

This information is required for the calculation of the CRP, and also for the analysis and definition of the PS of the components and final product.

The reference model, in BPMN notation, for the MRP module is shown in Figure 5.

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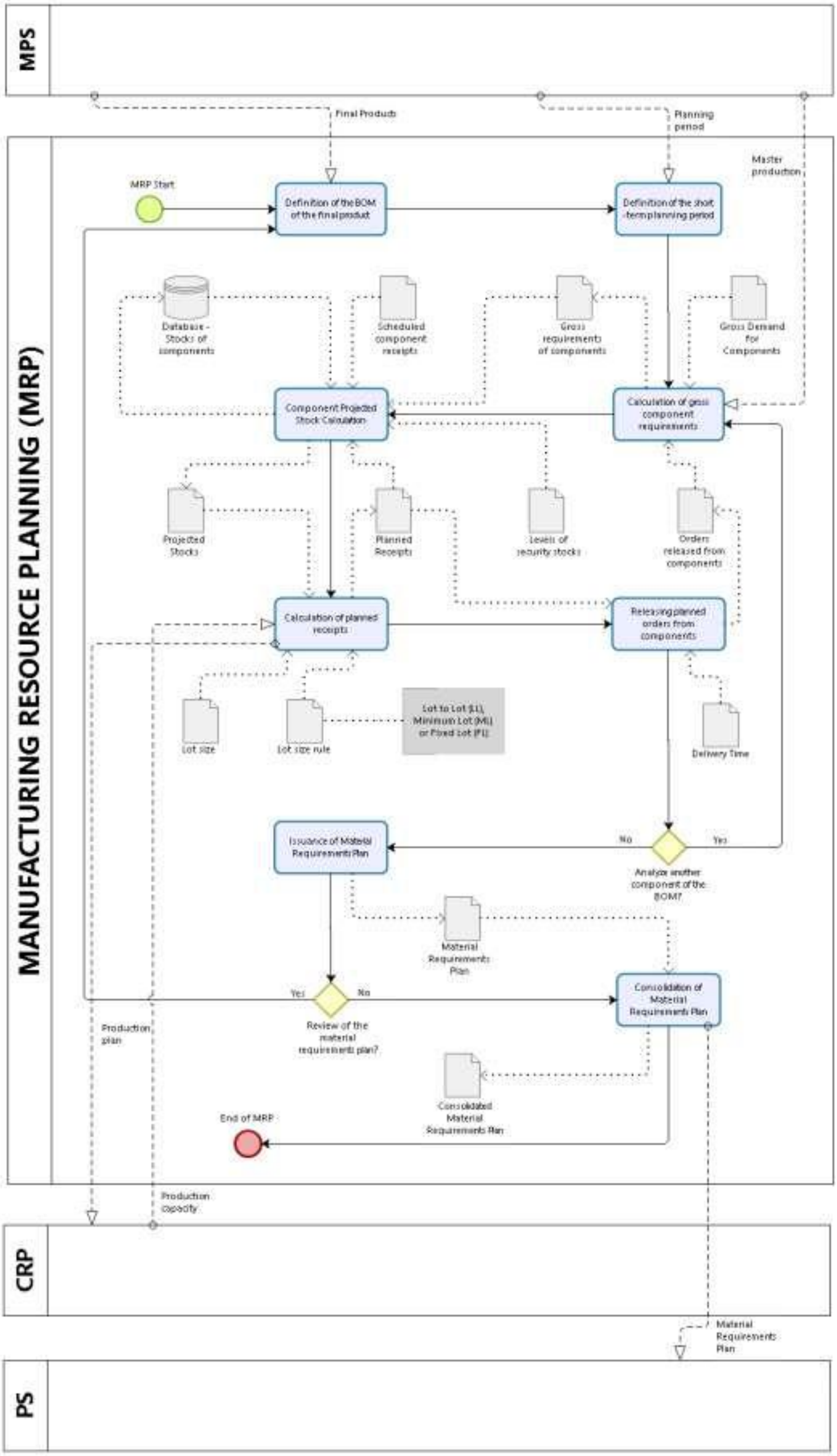

Fig. 5: Modeling of MRP in BPMN notation

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4.2 CRP MODELING

The CRP aims to subsidize the decisions of the detailed planning of the production and materials. This planning has the objective of calculating resource needs that require a few weeks to mobilize and also the generation of a detailed production plan that is viable, through adjustments made in the original plan suggested by MRP, so that this can be released for execution.

The input and output information required for the elaboration of the reference model of the CRP module are shown in Table 3.

Table 3: CRP information

Input	***Output***
List of materials of the final products	Capacity required
Short-term planning period	Capacity installed
Working days	Charging rate
Daily working day	Short-term production capacity plan
Amount of labor	
Quantity of subcontracted labor	
Overtime of daily work	
Setup times	

The activities related to this module of the PPC planning are presented, with their respective theoretical references, in Table 4.

Table 4: Sequence of CRP activities

#	Activity	Theoretical Framework
1	Definition of the BOM of the final products specified in MRP.	Girotti et al. (2016), Corrêa & Corrêa (2012), Moreira (2008), Gaither & Frazier (2005), Yenisey (2006) and Neely & Byrne (1992).
2	Definition of the planning period specified in MRP.	Corrêa & Corrêa (2012).
3	Survey of the following information regarding productive capacity: quantity of labor (normal and subcontracted).	Corrêa & Corrêa (2012), Corrêa, Gianesi & Caon (2009), and Mukhopadhyay (2013).
4	Survey of the following information regarding production time: daily working day, overtime and working days of each planning period.	
5	Survey of the production rate of final product components.	
6	Calculation of the necessary production capacity of the components.	Corrêa and Corrêa (2012).
7	Calculation of installed production capacity.	
8	Calculation of the loading rate.	Corrêa & Corrêa (2012) and Vollmann (2005).
9	Elaboration of the short-term production capacity plan.	Martins & Laugeni (2009).
10	Review of the short-term production capacity plan, if necessary.	Mukhopadhyay (2013) and Corrêa, Gianesi & Caon (2009).
11	Definition of the BOM of the final products specified in MRP.	

In the CRP model, as shown in Figure 6, the short-term planning time is initially defined, according to what was established by the MRP.

Next, the total setup time for all BOM materials present in the production process is calculated.

For calculating the required production capacity, account is taken of the quantity of materials of the final product to be planned that are described in the receipts planned in the material requirements plan. In order to make this calculation, it is necessary to have information on two variables relevant to the production process: the production rate of these materials, the amount of labor available (normal and subcontracted), the production plan specified in the MRP, and total times calculated in the previous step.

Following the description of this stage of the model, the production capacity is consolidated, which for calculation should take into account the following variables: working days, working hours and overtime, the latter if there is .

Finally, for the calculation of the loading rate of the production process related to the MRP, which is performed by the ratio between the total required production capacity and the installed production capacity. After the completion of this last stage, the short-term capacity plan, necessary for the consolidation of the MRP, is issued. In case of need, it is possible to carry out a review of this plan elaborated. After the review, then, the consolidated plan of the CRP is issued. This

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information, as previously seen, is required for MRP analysis and definition.

The reference model, in BPMN notation, for the MRP module is shown in Figure 6.

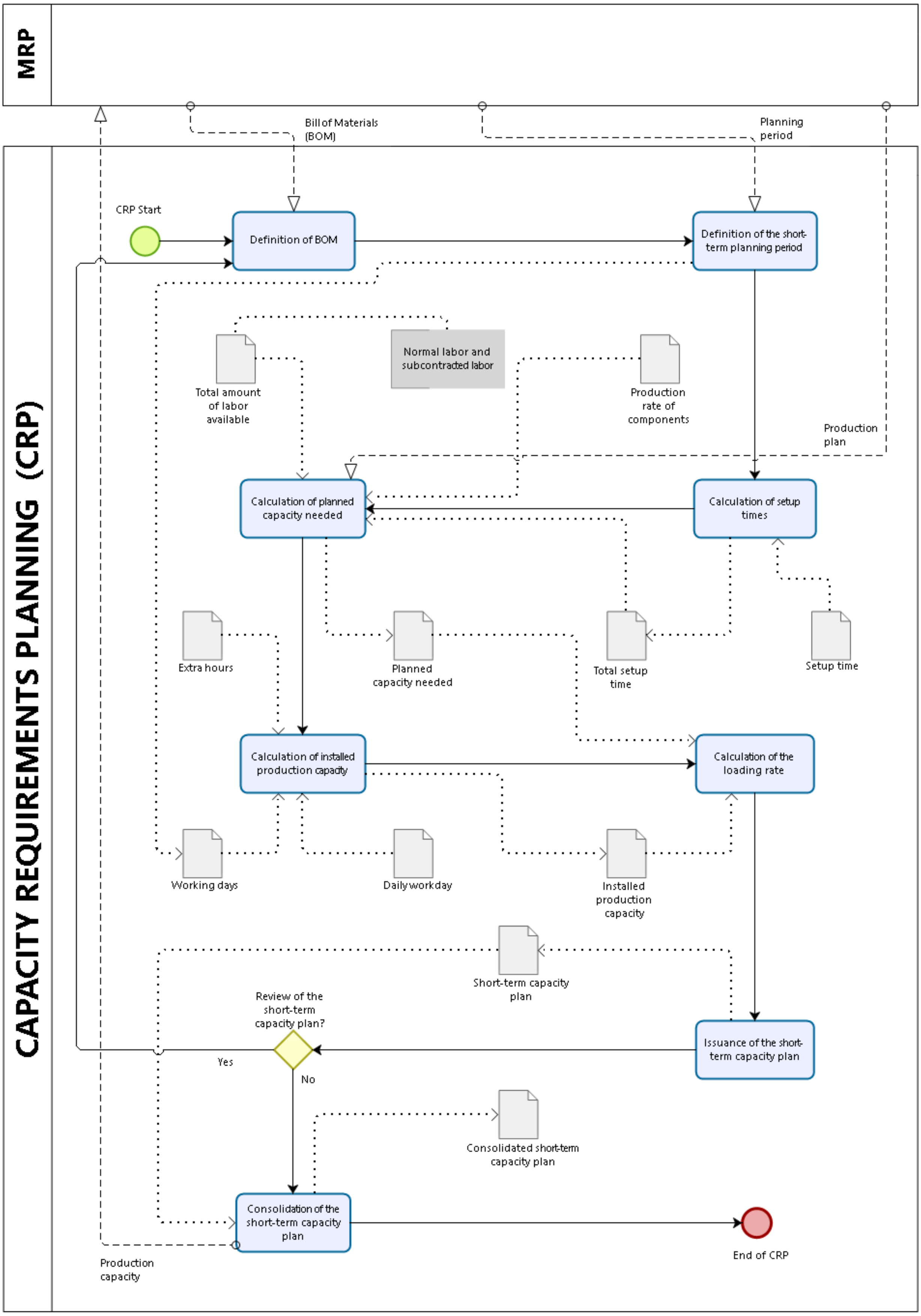

Fig. 6: Modeling of CRP in BPMN notation

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4.3 SOFTWARE PROTOTYPE

After the elaboration of the production planning system module for MRP and CRP, a software prototype was developed through the Delphi interface, with the intention of generating a greater consistency between the abstraction of the reference model and its application in the support of implementation and development of enterprise management tools, a software prototype was developed through the Delphi interface.

The first screen of the prototype for MRP and CRP is being shown in Figure 7.

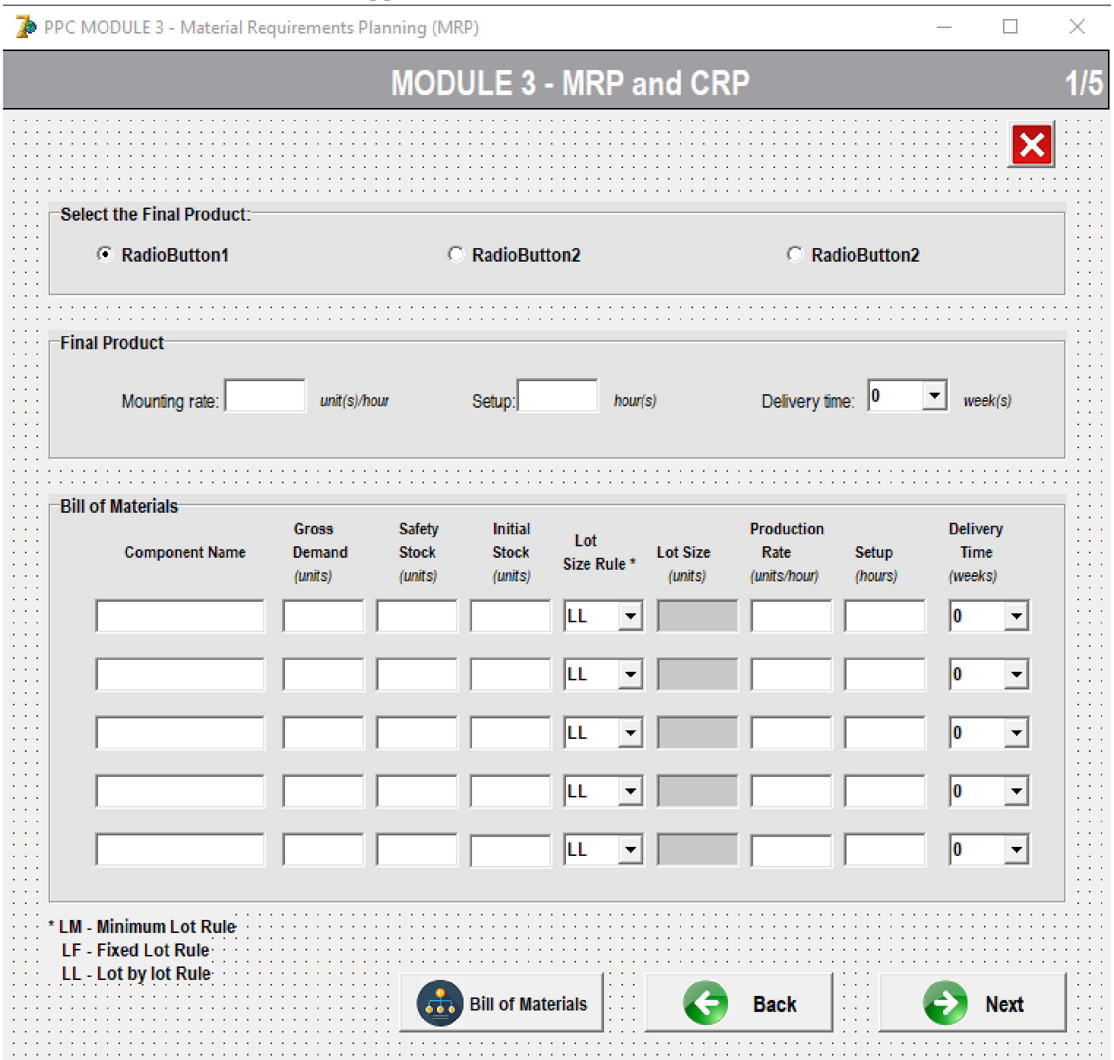

Fig. 7: First screen of the computational program of the MRP and CRP module

In order to validate the software prototype, several tests were carried out, with different planning scenarios and production strategies, in order to verify the activities, information, accuracy and precision of the calculations used to prepare the final master plan .

The results obtained by the computational program were compared with the results extracted manually and in electronic spreadsheets. Thus, the software prototype developed from the developed reference model proved to be reliable and apt to be used for the preparation of production material requirements plans.

V. CONCLUSION

Currently, we are seeing increasing attention in the support to the development and implementation of actions of improvements of the business management. However, most research and solutions for production planning are focused on large and complex organizations, highlighting an academic gap regarding work to support the implementation of management systems, especially for small and medium-sized enterprises. Therefore, the reference model developed in this work may provide these companies with an initial solution for their business processes, in order to specify and detail the particular model with a reduction in cost and implementation time.

Thus, this work sought the development of a reference model, in BPMN notation, that addresses the business processes related to MRP, as well as to CRP, one of the modules inherent in the PPC. In addition, we also aimed to develop a software prototype with the aim of applying this model in systems and management tools.

As a result, from a formal documentation, the reference model proved to be a useful tool in understanding and communicating the existing processes in MRP and CRP. It was also verified that this developed model is able to support the implantation of production management systems in real situations. However, for use in corporate environments, such as ERP adoption, these processes should receive the expertise and the users should have knowledge of the terms and variables involved in the reference model.

It is worth mentioning that the reference model has been configured as an important tool for knowledge management, since it is capable of storing and documenting existing knowledge in the business processes and serves as a basis for planning the development of new knowledge, always being guided by the strategic objectives of the company.

As a continuation of this work, a model is being developed that approaches in a holistic and hierarchical way the other modules of the Business Processes related to the PPC. Thus, this reference model seeks to fill gaps in the scientific literature and to advance in relation to international models, since there is a lack of work on reference models for the activities of the PPC.

For the purposes of validation and evaluation, it is suggested the dissemination and application of the software, developed from the reference model, in small and medium-sized enterprises with activities focused on production planning.

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