A Combined Method to Production Planning analysis and control Systems in Industry

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Abstract — ***Critical to achieving optimal operational efficiency is an integrated production planning and control system. However, most small manufacturing companies are yet to fully exploit the benefits of these systems due to the lack of financial capabilities as well as the expertise required for its adoption. In addition, most "off-the shelf" applications available have been unable to adequately integrate the different planning levels; thus, the specific needs of these dynamic, flexible and unstructured companies have not been captured. This makes an in-house development approach an attractive alternative. Hence, this research outlines the framework for development of a customized application for production planning and control in a small- scale industry. This application, developed using IDEF0 framework, is a low-cost, dynamic and user- friendly decision support tool, characterized by strong statistical capabilities to make accurate forecasts based on historical data and inventory control using three lot-sizing techniques. The core design principles implemented are integration, flexible user-interface and simplicity achieved through Visual Basic Application, whilst using Microsoft Access for the database. The results show that this methodology is highly recommended for projects that involve integration of information systems. Also, small businesses can adopt this to design and develop a customized integrated production planning tool using minimal time and capital.***

Keywords — ***Manufacturing, Control, Planning, MPS, Production.***

I. Introduction

The dynamic nature of businesses today is becoming increasingly complex, with a budding need for inter-departmental data flow within the core business units for accurate decision making, inventory management, timely procurement of parts and distribution of goods [9]. Hence, an efficient information system is of utmost importance. This holds true for both large enterprises as well as Small and Medium Enterprises (SMEs) [2]. Enterprise Resource Planning (ERP) systems which is also an extension of Manufacturing Resource Planning allows the combination of different sub-systems into one massive system having a centralized database [1]. This allows a swift flow of information throughout the organization [2, 9]. In fact, ERP facilitates standardization of the organization by ensuring the company adheres to the system-prescribed approach in order to optimize resources [2]. Over the years, production planning has evolved; it started off as Materials Requirements Planning (MRP) using the Master Production Schedule (MPS), this was used to design the raw material requirements in a manufacturing environment. After a while, it advanced into Manufacturing Resource Planning (MRP-II) which was basically MRP plus scheduling and capacity planning activities [3]. An MRP-II system can be used to effectively plan and integrate the resources required for manufacturing the products of a company. ERP system is an extension of MRP-II with an extension that incorporates Finance, Supply Chain, Human Resources and Project Management functionality [3,4]. The key distinguishing factor between MRP-II and ERP is that while the former, MRP-II is primarily focused on the planning and scheduling of internal resources, the latter, ERP goes an extra mile to incorporate supplier resources as well, to accommodate the dynamic nature of customer demands.

This new ERP system encapsulates integration both internally and externally, linking systems together along the entire value chain [3]. In fact, this allows a great interaction between the customers and suppliers which in turn enables the companies to produce goods that conform to customer specification [9]. ERP systems equip organizations to integrate all the core aspects of business operations processes such as production planning, purchasing, financial cost accounting, materials management, sales and distribution, human resource and customer service, etc. in order to enhance efficiency as well as maintain a competitive edge [2, 5, 7]. ERP systems allow accurate calculation of material, capacity and resource requirements to be used for manufacturing, initially and concurrently [7]. Furthermore, ERP facilitates a seamless communication of common functional information across the entire business, enhances supply chain management and reduces cycle time [5].

There are 7 basic modules incorporated in any ERP system namely [9]:

- ERP production planning module
- ERP purchasing module
- ERP inventory control module
- ERP sales module
- ERP marketing module
- ERP financial module
- ERP human resources module

1.1 Benefits of ERP

There exists several literature enumerating the diverse benefits of an ERP system in a manufacturing environment, amongst which include; maximizing operational effectiveness and efficiency [3, 9], improved supply chain management [2], inventory and labor cost reductions [3] and increased competitiveness [7]. For a competitive advantage ERP system can provide organizations with improved business performance [44]. Gartner Group [45] also mentioned the intangible and tangible benefits of ERP with claims of improved financial management, reduced cycle time and faster information processing by some companies. A comprehensive framework of the ERP systems' benefits was provided by Shang & Seddon [46] by carrying out a survey of 233 vendors with 34 phone interviews for follow-up using the websites of three major ERP vendors. Figure 2 shows the ERP benefits framework and their extent of tangibility and quantifiability of the five categories. The categories were largely built on operational efficiency, managerial and strategic effectiveness. This provides a sort of checklist for the benefits that have been accomplished by organizations using enterprise system.

II. LITERATURE REVIEW

As a result of the rapidly changing technology, ERP system designs have evolved over time, transitioning from traditional ERP (MRP) to cloud-based and mobile ERP systems [2]. As mentioned earlier, an ERP system can integrate several functional areas of operation, e.g., sales & marketing, supply chain management (production planning, material management, capacity planning etc.), accounting & finance, and human capital management [4].

Although the potential benefits of an ERP system are compelling, its implementation remains a daunting task for many organizations. The cost of purchase and implementation spans from hundreds to millions of dollars and the process can take 10 months to several years [15]. Since ERP systems are equally useful to the SMEs, this cost factor makes it unaffordable for them in addition to the drought of the required expertise for implementation of these systems [2]. Ruldeviyani and Sandhyaduhita [6] designed an ERP system for SMEs with a focus on the sales business function area using a waterfall process model. Ghorpade and Mantri [13] also designed an ERP system for small scale businesses with a focus on production planning in a make-to-order environment. In their research, forecasts were made based on exponential smoothing and linear regression method only. It is evident that there is a need to provide a small-scale ERP system that is relatively easy to implement and use by the SMEs. The key outcome of the research has shown that even SMEs can design and implement their own MRP-II system, which is specific and relevant to their own special manufacturing environment, using a minimal of time, software and financial resources.

This research would focus only on the production planning & control function area as one of the most important areas for SMEs. There would be an exploration of more forecasting methods to ensure the best forecasting method that minimizes error is chosen. In lieu of this, an ERP system that supports the production area is designed. The proposed ERP system uses Microsoft Access as the database, Microsoft Excel for the calculations and Visual Basic for Applications (VBA) for the design of the Graphical User Interface (GUI).

2.1 Production Planning and Control (PPC)

The major aim of Production Planning and Control (PPC) is to optimize the utilization of all manufacturing resources (workforce, capacity, material etc.) using historical data and sales forecasts [9]. This involves an efficient utilization of raw materials, human resources and facilities such that all production activities culminate in an optimal combination. In a research by Gore et al. [8], it was reported that production planning allows the planner to generate feasible production plans to fulfil the demand requirements, in time and equally meet the expectations of the consumer. There are 5 major levels of management in production planning and control: business planning, sales and operations planning, master production schedule, material demand planning and capacity planning. These different levels are harmonious; the feedback of one level serves as an input for another [28]. PPC employs the use of a hierarchical structure for planning with the forecast data representing the highest level [10,13]. The forecast data, which is the targeted demand to be fulfilled, forms the basis for generating the production plan called the Master Production Schedule (MPS) which is a plan for the individual products to be manufactured in a given period [28]. The output of the MPS, planned orders for the end items (gross primary requirements), serves as an input for the Material requirements planning (MRP). The MRP which is a derivative of the MPS, uses the MPS to calculate the secondary and net requirements for all of the subassemblies and parts needed to make that item whilst taking inventory into account. Its main objective is to ensure that there is an adequate supply of materials for production and products are available to be supplied to the customer [28]. Once these materials-focused tasks are completed, a capacity requirement plan integrates the available machines in the planning process [14]. Capacity requirements planning (CRP) is the process of determining the production capacity needed to meet a dynamic demand [28]. Figure 3 is a schematic of a detailed basic production planning and control system. For the sake of the design of this project, this ERP system would be divided into 5 submodules namely: Forecasting submodule, APP submodule, MPS submodule, MRP submodule and CRP submodule.

2.1.1 Forecasting

As the name implies, Forecasting is a method of estimating future demand with the sole aim of controlling supply [16]. Adequately described as a strategic resource planning technique by [16] and a backbone of fruitful operations by [18], forecasting is a planning tool which involves working with internal and external stake holders to estimate product requirements that satisfy customer demand. Forecasting forms the basis of any production planning process as it serves as the first input into the planning system [13]. According to Sahu et

al. [17], "Forecasting is defined as the prediction of future events based on known past value of relevant variables".
The accuracy of any forecast is crucial for effective planning; it prevents the unnecessary inventory and smoothing planning issues which subsequently lead to increased productivity and profit [18]. Over- forecasting and under-forecasting are undesirable in any production environment as either of both would lead to poor management decisions [17]. Forecasting is a technique that has been widely used across several industries for predicting price of a commodity, energy consumption of a country, demand of a product, unemployment rate and so on [18].

2.1.2 Master Production Schedule

Aggregate production planning serves as an intermediate planning level, however, to translate this production plan into meaningful terms for production, there is a need to disaggregate the plan [32]. Disaggregation means breaking down the aggregate plan into specific product requirements. The result of this disaggregation is called a Master Production Schedule (MPS). The major aim of an MPS is to be able to generate a specific labor, material and inventory requirement [32]. MPS can be accurately defined as the conversion of an aggregate production plan to create a schedule for specific end items [13] . It is a plan for the individual products to be manufactured over a given period [28]. As the name implies, MPS provides the production schedule as well as the available-to-promise (ATP) of the end items [30]. It is also known as the primary input into the MRP system. It gives information on the parts, processes and other resources required for production avoiding bottlenecks as much as possible and ultimately optimizing production [28]. Noteworthy is the fact that the accuracy of an MPS would invariably affects the viability and profitability of any organization [28]. The input data required for an MPS are: demand forecast for end items, inventory levels for end products, safety stock, lot-sizing policy while the outputs are planned on- hand inventory and production requirements. Simply put, MPS provides a micro plan for production [30]. According to Lalami, Frein and Gayon [31], MPS is a more detailed production planning process compared to the APP owing to the fact that, the level of product aggregation, the length of the planning horizon, as well as the size of the time buckets in which the planning horizon is divided are more comprehensive. For example, an aggregate plan at end-item level is divided into monthly time buckets, while the MPS is performed on a weekly basis [31]. Essentially, this process of planning management calculates the amount of products needed based on the customer orders or forecast and the time required to achieve this based on need time and lead time of the product [38].

2.1.3 Materials Requirement Planning (MRP)

Materials Requirement Planning (MRP) can be defined as the process of planning the raw material requirement to translate production plans into series of specific plans [30]. It is a planning strategy used to schedule the production of the dependent demand items from the independent demand items using BOM explosion, netting and offsetting [34]. Thus, it can be described as a technique for determining the quantity and timing for the acquisition of dependent demand items needed to satisfy master production schedule (MPS) requirements by converting the bill of material, inventory master file and master production schedule into time-phased requirements for subassemblies, component parts and raw materials, working backward from the due date using lead times and other information to determine when and how much to order. It has been widely accepted as a production planning and inventory control mechanism [49]. It is a logical procedure involving decision rules and computer based techniques used to translate gross requirements obtained from the MPS into net requirements for all sub-items [36]. Simply put, it is used to decide what, when and how many component and material needed for production planning [36]. The major objectives of any MRP system are: to ensure the inventory levels are maintained at the lowest level, ensure raw materials are available for production when needed, to reduce the risk of late production or delivery and to plan purchase & manufacturing activities as well as delivery schedules [35,49].

2.1.4 Inventory Control Method

As stated in Andwiyan et al. [36], MRP ensures that the lowest possible material and inventory level is maintained, which implies that inventory control is a crucial aspect of an MRP system. Inventory is any resource such as raw materials, finished products, component parts, supplies and work-in process used in an organization. Efficient inventory management would result in a reduction in the costs associated with changing production rates, overtime, sub-contracting, loss of goodwill etc. during periods of dynamic demand [39]. The main aim is to avoid holding too much or too little inventory. Inventory control has been identified as an important variable in MRP system design [49]. Selection of lot-sizing technique based on the lead time, should simultaneously satisfy demand requirements as well as minimize holding and setup costs.

2.1.5 Manufacturing Resource Planning (MRP-II)

A stand-alone MRP system is sufficient for production planning when there are no capacity constraints, however when manufacturers discovered an additional need to plan the capacity required for production, Manufacturing Resource Planning (MRP-II) was developed [32]. MRP II is an extension of MRP to include capacity requirement planning (CRP) and other functional areas of the planning process such as marketing and finance [42]. It can be defined as a production resource planning process involving a more detailed capacity requirements plan to assess how production targets can be met with the available capacity [32]. A key component of the MRP-II is the feedback loop, which allows revision of non-feasible plans before they are executed and provides simulation capacity such that the user can ask "what if' questions relevant to the production plan [42]. MRP- II allows the development of a detailed production

2.1.6 Capacity Requirements Planning

Capacity requirements planning (CRP) is a planning method capable of confirming whether or not there is enough production capacity to satisfy the production demand [43]. It is used to check the feasibility of a production plan; hence it is an important feedback link into the MRP-II. Basically, CRP is used to estimate the available capacity and confirm relevant measures to balance production capacity and production requirements [43]. It tells whether the capacity should be improved or not [13]. The major outputs include load reports for each work center. In a case where there are underloads or overloads, the planners can manage this by changing lot size requirements or safety stock requirements etc.

III. RESEARCH METHODOLOGY

This In order to achieve the proposed integrated solution, an IDEF0 approach was used to model the MRP-II concept showing the important feed forward and feedback relationships between the production modules. First, the business rules and logic based on MRP-II concept are specified then the framework is designed. The attributes of this framework include hierarchal simulations, planning hierarchies, a management information system (MIS) and a set of feedback loops. These feedback loops are an integral part of the system because it ensures that the process can be modelled to demonstrate how a change in one part affects the other parts. For example, if there is a capacity constraint, the feedback from the capacity requirements module can be used to adjust the MPS accordingly.

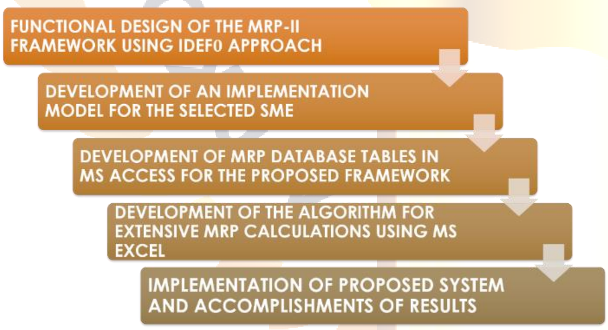

Figure 1: Proposed methodology for the research

3.1 Developing the System using IDEF0 Approach

One of the research objectives of this work is to design an integrated PPC system. The functional model for this is represented in Figure 1. This functional model states clearly the aim of this study which is to design an integrated PPC system. The ICOMs are also specified. Thus, the top-level diagram (A0) is produced. Noteworthy is the fact that an IDEF0 model should be designed based on one defined perspective, this ensures clarity and focus on the design problem. Any deviations from this reduces the quality of the model [58].

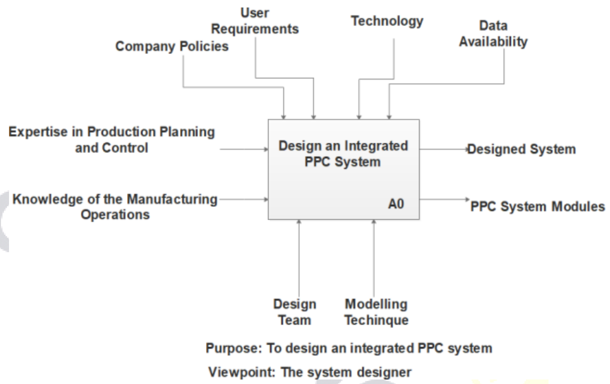

Figure 2 : System design using IDEF0 approach

The design of an integrated PPC system follows a series of processes as shown in Figure 2:

- Analyze and Identify System Requirements (A1)
- Initiate PPC System Design (A2)
- Test and Evaluate PPC System (A3).

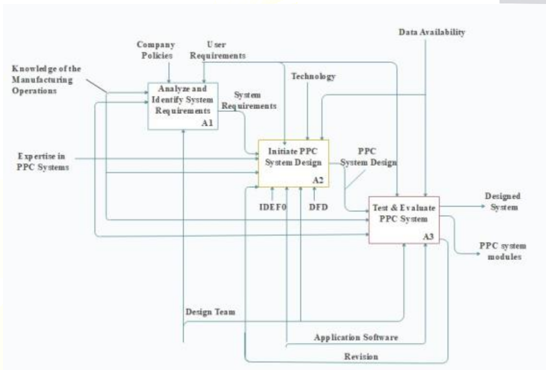

Figure 3 : Decomposition of node A0

From Figure 3 above, it follows that the output of a later activity/process can be used to revise earlier processes. These steps are expedient for any company that wants to implement this methodology.

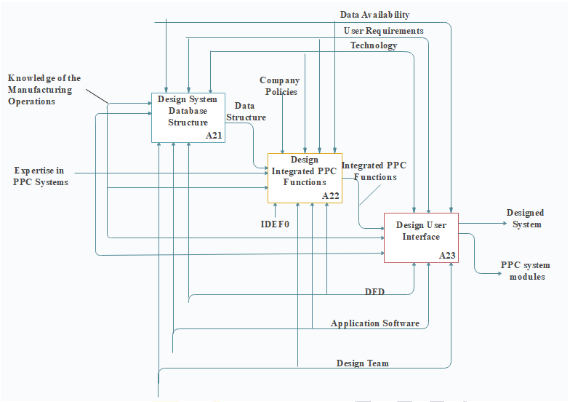

Figure 4 : Main steps of the methodology to initiate a PPC system design

The first step to initiate a PPC system design (A2), is to design the database structure (A21) which involves designing the database tables as well as defining the relationship between the entities. The Then, the next step is to design the integrated PPC functions (A22), this step allows creation of customized modules applicable to the SME. Afterwards, the next step is to design the user interface (A23) using Excel VBA. This process involves generation of design ideas incorporating design principles such as integration, flexibility and ergonomics. This decomposition of node A2 is shown in Figure 4.

The model described above shows how the different functions of PPC are inter-related, as well the modules which are the outputs of each function boxes . The information provided from these loops are critical for reconciliation of the conflicting objectives between production, marketing and finance in decisions concerning acceptance of customer orders, placement of production and procurement orders, variations in capacity, and allocation of available capacity that exists in manufacturing environments[52]. Similarly, Bonney [48] modelled the PPC framework using a similar approach.

3.2 System Algorithm Description

This section provides a summarized description of the system algorithm. This system has been designed with capabilities to forecast demand using four different forecasting techniques, develop an aggregate plan using the Level and Chase strategy, vary lot-sizing techniques for the material requirements plan and plan capacity. The planning horizon implemented was for a period of one year each divided into weekly buckets. This indicates that further scalability is possible; the planning horizon can be adjusted to represent quarterly or yearly demand. The steps involved in the algorithm are outlined below:

Step 1: Select the product from the drop down menu. Then select the forecasting technique to be employed. Then the best method is selected based on minimal forecast errors.

Step 2: After generation of forecasts for the planning horizon, the user proceeds to the aggregate plan. User provides data such as on-hand inventory, beginning workforce, safety stock, production per worker as well as the related costs. Based on this data, the costs of implementing a Level and Chase strategy can be calculated.

Step 3: User proceeds to MPS module. First select the month, the lot-sizing policy for the item, on-hand inventory and safety stock

Step 4: The user can also decide to edit demand to generate a new MPS and save the results to the database Step 5: Based on parent- child relationship in the BOM and optimal lot-sizing technique, user can run the program to generate the material requirement plans for gross requirements (GR), net requirements (NR), planned order receipts (POR) and planned order releases (PORel) .

Step 6: In the case of infeasibility, the user can change the lot-sizing rule or adjust the MPS until a realistic schedule is developed.

Step 7: User selects the work center, specifies total number of workers, working hours per day, working days per week, labor utilization factor, labor efficiency.

Step 8: Click calculate to generate the effective labor capacity for each work center as well as the required labor capacity for each period in each work center as indicated in the planned order release.

Step 9: A chart output is generated which represents the load profile is generated for each work center. Step 10: If the required labor capacity is less than effective labor capacity, then it means the plan is realistic and can be implemented.

Step 11: However, if the required capacity is greater than the effective labor capacity, the user can simulate different scenarios such as increasing the total number of workers or working hours (overtime) until a realistic schedule is attained.

3.3 System Testing

Practical analysis and validation of the system was carried out using data from a small toy manufacturing company [59]. The case study industry is a small scaled manufacturing company that produces three products: a toy racecar, a toy dump truck and a toy tractor. This company operates as a Make-to-Stock (MTS) production environment. There are three manufacturing departments in this company namely; Assembly, Finishing and Packing. The finishing department receives precut, unfinished body parts for each product. These parts are sanded and painted to make the finished body parts. The past year’s demand for the three products are provided. Data on the current inventory levels are also provided. The performance of this software was tested and verified using these data provided. Critical to quality for this application include: integration, flexible user-interface and simplicity which was achieved using Visual Basic for applications.

IV . RESULTS AND DISCUSSION

In this chapter, the results of application of the proposed methodology to a case study is shown. The case study is a small manufacturing company dealing with assembly of toy-cars, toy-trucks and toy-tractors. The IDEF0 methodology is applied to develop an integrated production planning tool and the delivery of the methodology is accomplished through a spreadsheet application and a flexible user interface designed using VBA. The results are detailed in the following sections.

4.1 Forecast Module

This subsystem uses historical demand data gotten from the database, to forecast the demand for the next month up to 12 months using Moving average, Exponential smoothing, Holt's method and Winter's method of forecasting. An important feature of this module is the measurement of forecast errors using methods such as Mean Absolute Deviation (MAD), Mean Absolute Percentage Error (MAPE), Mean Squared Error (MSE). The user selects the end-item to be forecasted, period, as well as the forecasting method. The output is shown in Figure 5.

Figure 5 : Forecasting module

4.2 Aggregate Production Planning Module

Aggregate production planning module uses output from the forecast module to generate an aggregate production plan. Data such as on-hand inventory, safety stock are gotten from the database while the user inputs other variables such as hiring cost, firing cost, overtime cost etc. Once the necessary information is filled, the user generates a plan using these two strategies; level strategy and chase strategy. Figure 6 shows the output of the APP module. Based on the estimated costs of both strategies, the user can make a decision on which method suits the company goals.

Figure 6 : Aggregate Production Planning module

4.3 Master Production Schedule Module

The Master Production Schedule is responsible for the conversion of aggregate plan into a schedule for end items. The MPS is a very crucial module because it is a primary input into the MRP system. The APP system generates a monthly plan for the end item while the MPS generates a weekly production requirements. The user selects the end-item, month while the other required data are gotten from the database. An important feature of this module is the "Edit Demand" button which allows the user to simulate the effect of a change in demand requirements over the planning horizon. Figure 7 shows the output of the MPS module.

Figure 7 : Master Production Schedule module

4.4 Inventory Records Module

This module enables the user view inventory reports about every item in the database. It gives information about each part in the inventory without having to go into the database. Also, information about the subcomponents that make up an assembly can be viewed in this module. Figure 8 shows the output of the inventory records module. The user also has the option to edit the details of a part and the results are reflected in the database.

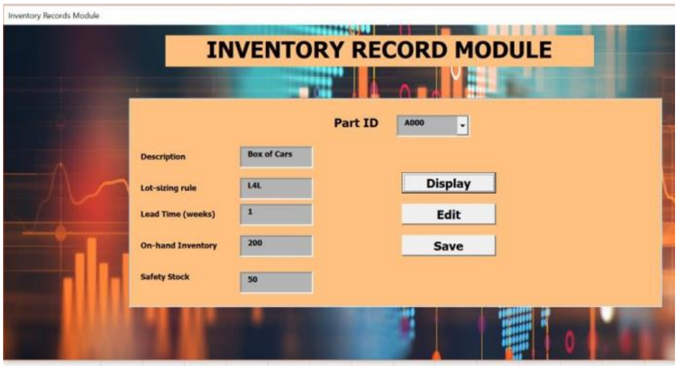

Figure 8: Inventory Records Module

V Conclusion

An IDEF0 methodology as an engineering approach, was used to design an integrated PPC tool for a small toy manufacturing company. This methodology was implemented by using a database system and a spreadsheet to create a hybrid PPC system [59]. The adoption of this model ensured that the inter - relationships between the modules in a PPC framework were designed with clarity and effectiveness, achieving the desired integration necessary for achieving strategic business objectives. The findings from this research corroborate the fact that adoption of IDEF0 methodology is strongly recommended for projects that require a modeling technique for the analysis, development, integration, re-engineering or acquisition of information systems [54]. Through this adoption, improved productivity and enhanced information flow in computer integrated manufacturing systems can be achieved.

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