Business Processes and Systems for Small and Medium Sized Businesses

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Background

Prior to the advent of computers, and even after computers were becoming available, large-scale data systems were not commonly available or used. This meant that local tribal knowledge continued to play a pivotal role in operating businesses. As engineering design evolved from drawing boards to Computer Aided Design (CAD) and more formal approaches to materials planning, computer systems began to emerge that provided more effective and efficient management of the growing amount of data being generated and used.

Materials planning (MRP) and manufacturing scheduling evolved into Manufacturing Resource Planning (MRP II) and then Enterprise Resource Planning (ERP) and CAD data management evolved into Product Data Management (PDM) and then Product Lifecycle Management (PLM). Later, Manufacturing Execution Systems (MES) became more commonplace. As systems grew to encompass more functions, more and larger computer-based systems became available. Inevitably as this occurred, the lines between systems are often blurred. Systems that started life as ERP systems started to acquire elements of MES. Likewise, MESs acquired what had been traditionally ERP functions. This is exacerbated by the desire of the software vendors to grow their market share, by expanding the functions offered in their product. This makes it more difficult for companies to sort through the maze and acquire tools that meet their needs in a sustainable and scalable way. This paper is an attempt to identify the salient features typically used in manufacturing and to ultimately help identify the features needed and to then inform the choice of the appropriate software to meet those needs.

While software companies design their products to meet what they perceive to be the needs of industry at large, there cannot be a one size fits all solution. As such, software and approaches that may work very well for one business may not be appropriate for others. The nature of an offering is influenced strongly by perception of market need. As such it is often wisest to consider the specific requirements of a specific company when trying to determine how best to manage data and ultimately support use of that data in software systems. A capability matrix defined by practitioners is the best practice used to define the requirements of such systems. This requires clear understanding of both functional requirements and prospective software capabilities. This document is intended to create a more complete understanding of the purpose of each function discussed such that the impact on the business can be better evaluated.

As a means of achieving this goal this document discusses of support for business processes using PDM, PLM, ERP and MES systems. In order to operate successfully, a business must have all critical functionality supported by a software system. However, choice of system support for a particular process is not universal; functions may be supported by different software systems in various companies.

Before launching into descriptions of functionality, it is important to first discuss the topic of master data and master data management. The basic concepts of defining data once and using many times will be emphasized throughout this paper. This concept forms a fundamental basis for data governance. Data governance is important because it defines what data originates in which system, who is authorized to create and modify it as well as where it is also used and by whom. In other words, it completely defines roles and responsibilities for data creation and use. This requires that the system within which that data is created should be mapped, as well as the systems in which data is used. The definition, management, and governance of master data ensures accurate and error free usage of data wherever it is needed within the enterprise. In turn, this allows all users of data within the company to have access to data that is complete and consistent in every process in which it is used. This eliminates poor decisions that could otherwise result from incomplete or inaccurate data. Systems that lack data integration often suffer from this problem.

The notion of product definition and configuration data versus transactional data will also be addressed. Full integration of data systems ensures data integrity and minimizes errors, as well as avoiding non-value-added work associated with maintaining different versions of what should be the same data.

System of Record

For the effective and unambiguous definition and production of a product, it is essential in well-integrated business systems to clearly define the system of record for all data and documents. It is not uncommon in many businesses, in which business process integration is loose, to see the same data redundantly defined and stored in multiple software or other systems. While this is often perceived as convenient or necessary, it forms the basis of a locally optimized solution. The goal is a globally optimized business process. This demands adopting a "single source of truth" for data as a standard company policy. In most cases where this has not been achieved, the situation has arisen organically over time and may not be apparent to those within the business with an eye on tactical execution. Groups who need to consume data often re-enter it to serve their local purpose. The results in having different versions of the "truth" and can lead to poor decision making. It is essential in modern business to create data in one system and then share it throughout the enterprise through automated connections that update the data on a regular basis. The frequency of the update varies depending on the data and the cadence of the company, as well as the nature and volume of the product being produced. This requires that a conscious effort be applied to defining the system of record of each data element (and/or document). In turn, this requires that a data governance model be defined to ensure that data owners are defined and are the only people authorized to add or change only certain pieces of data.

As an example, Engineering should always be the owner of part number definition for parts that define the product. In situations in which others can enter part numbers it is common to see wide variation in the way in which the part number is entered into a system. This can lead to loss of inventory control. Imagine a situation in which part ABC01-01 is defined by engineering. If in a warehousing someone introduces this part as ABCO1-01 problems occur. In this case the character after the C was changed from zero to the letter "O". Most people can parse this to mean the same thing, but data systems see these as separate numbers. Therefore, avoidance of this easy to make error is assured by automating the interface between the systems to ensure that the downstream system used the definition from Engineering. This also improves efficiency in that the re-entry step is now eliminated. The essential argument here is that we define once and reuse wherever the data is needed and avoid data re-entry and potential redundancy and error.

Data Types

Data types can be categorized broadly as being structural (product defining) or transactional, although there are numerous other ways to categorize data. For example, engineering data is always product defining, whereas ERP data is generally transactional. ERP does possess some business structural data, like plant definition, workstation definition, customer names etc. Manufacturing systems have a combination of structural and transactional.

Engineering therefore rarely captures transactional data (with perhaps the exception of data defining instances of product non-conformance) but focuses almost entirely on defining the non-variable product and product configuration data. When engineering does change product data it typically does so under engineering change control. When applied to product data engineering changes modify the product design and define the new revision of the product. This implies a new invariable form of the product. In other words, product data changes only when some change in design is needed to fix a problem, change that specification for performance, or simplify the product to reduce cost. These changes are relatively infrequent, whereas the transactional data captured in ERP or MES -type functions changes in real time and allows for calculation of key process indicators (KPIs) that allow management of the business itself as opposed to defining the product design.

Manufacturing uses structural data to define how a product is made and captures transactional data about each instance of the product produced. For example, transactional data about the actual production time for each assembly or batch of parts. ERP systems define some 'non-variable, or periodically variable' data like price and customer names, but handles the majority of transactional data like ordering, planning finance, inventory levels etc. ERP systems that are well integrated with engineering should **use** but not **define** product definition data.

These ideas become useful in defining the systems of record for each piece of data and which data system is best suited to managing and other gathering it.

Organization of this Document

This document is organized following the order implied by the diagram below, arranged from bottom up.

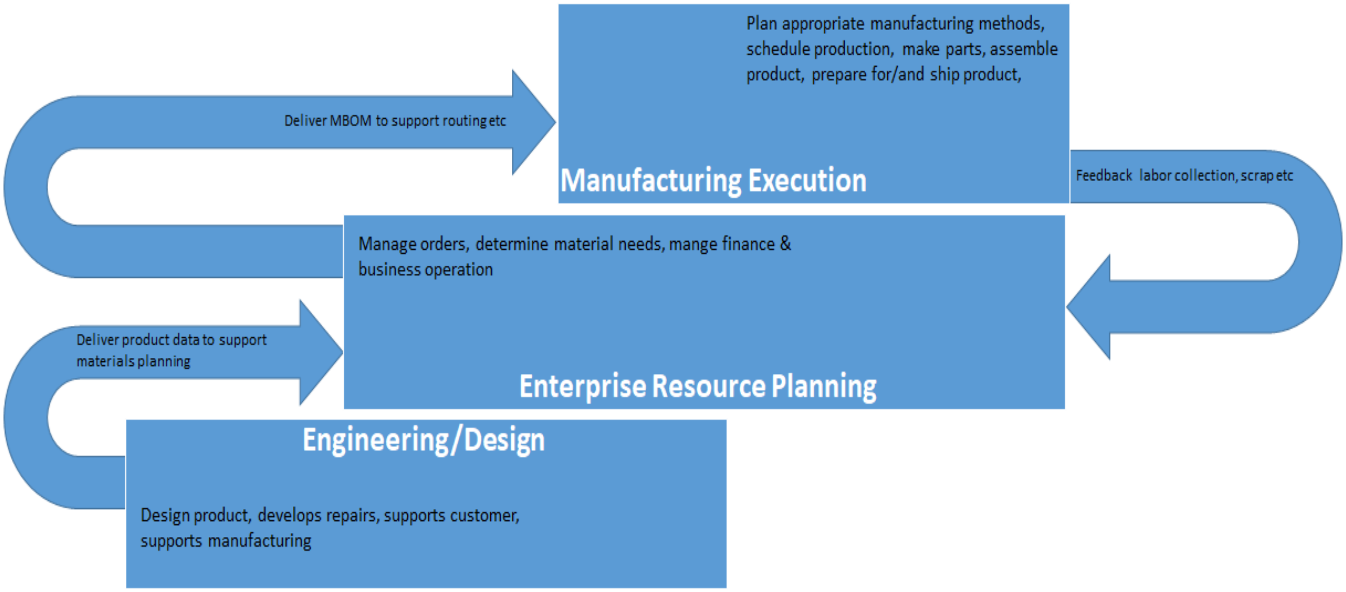


Figure 1: Business Process Flow

Data and processes that define the product are addressed first to establish a foundational layer for the processes of planning and business execution supported in the upper layers of the chart. Usually, the processes contained within each layer are often run concurrently once a new product has been introduced. It is therefore fair to consider this representation as that which would be typical at product start up and throughout product development.

There is no perfect graphical representation of how businesses operate since there are perhaps almost as many representations as there are businesses. However, for purposes of organizing our thinking and explaining data management and business process effectiveness, this representation is as useful as any. Incidentally, this chart contains elements contained in ISA-95, which is an international standard for manufacturing automation. The standard codifies some aspects of data management and the interfaces between systems, but it does not address the means by which such integration occurs. Its value is in identifying an approach to mapping data and compartmentalizing the processes often found in manufacturing businesses. Like many standards it tends to be useful as a reference when addressing specific problems. This document attempts to focus on an overall explanation of typical functional elements and type of data in plain terms as opposed to the computer science ideas found in some sections of ISA-95. That is not to say ISA-95 lacks value, simply that like many standards it can be viewed as a document written by experts for experts. We want to bring the discussion down to a more manageable and universal level. There is more explanation of ISA-95 in later sections of this work (pg.25).

Functions Supported by Data Systems

In order to achieve the goals of the business (exchange goods and services for payment), there are many different functions which individually must be accomplished. Understanding the data systems which help complete the order to cash process first requires a brief identification of the major functions in this process and the type of data they require, what type of data they own, and what data from one function may be required for another function. The approach below follows a rough chronological order of a theoretical order to cash process for a product, prefaced with the engineering definition phase.

Engineering Design

A pre-requisite for receiving a customer order for a product is the process of designing the product to meet the customer needs. Although many products are customized made-to-order and have some design function which may occur after receiving an order, a production design and definition is typically already complete. The process of transforming customer needs into product design is a subject which merits its own discussion and is a function that is often contained in broader PLM implementations. For the purposes of this document, a general approach will be taken with a focus on the system requirements for product design and documentation assuming clear customer requirements have already been communicated to designers.

The decisions that are required during the engineering design phase both require and generate data. The first decision required is an agreement with the design team and customer on the requirements. This typically requires data from the customer and a product requirements document of some type is often generated. For highly regulated industries (i.e., medical devices and pharmaceuticals, Aerospace and Defense) this may be a formal document which is part of the regulatory documentation of the product. In most industries, the requirements at the customer level are communicated in a more ad-hoc manor, and documentation and data generation does not occur until the **product requirements** have been transformed into **product definitions**. This distinction can be summarized as “what the product must do” versus ‘what are the product characteristics needed to satisfy product requirements’.

The data created, owned and shared from the engineering design function is product defining in one way or another. Typical minimum product defining data created and owned by the engineering function are:

- Product or Part Name/Number/Revision – This data should always be created and owned by the engineering function and is used extensively by other functions and often in other systems than where the data was created. Hierarchies and part models (groups of parts) should also be owned by the engineering function although they may require input from other functions.
- Bill of Materials – The list of needed components required to create a part should it be an assembly.
- 2D and/or 3D Part Definition – This is the data which defines what the actual part should be. Both a 2D drawing which will have controlled dimensions which produced parts must meet and in many cases a 3D part definition which fully defines the ideal state of the part.
- Material and Process Specification – Data which specifies the characteristics of raw material and process steps in order to meet customer requirements. Often this data controls characteristics of the part which are not explicitly called out on the 2D drawing such as material properties of the finished part.

The typical system which supports the engineering function is either a Product Data Management (PDM) system or Product Lifecycle Management (PLM) system. PLM systems are comprised of a core PDM system but are expanded to manage other functions beyond those of part number, drawing, BOM and specification management. More detailed discussion of these difference can be found later in this document.

Sales/Customer Orders

The purpose of the sales function from the perspective of the business is to generate and receive orders which drive the demand for product delivery from the business. From a data systems perspective, data will be generated which is typically either about a **customer**, or about an **order**. This function therefore includes both structural data and transactional data. The use of these two data types, while both owned by the sales function, is often different. For example, for the purposes of sales forecasting and customer relationship management, data which may be historically transactional, such as order quantity and timing, may be aggregated as customer-defining structural data. Another example of customer-defining data would be information about the drivers of the customer's sales in a business to business setting. Information about other competitive suppliers is also relevant to making decisions and analysis around the **customer's buying behavior**. This data is often managed in separate software or modules known as customer relationship management (CRM) software. Some customer defining data may be added to transactional data each time an order is received, such as customer shipping address or invoice ID.

This stands in contrast to data which is generated to support a specific order. This data may also be considered owned by the "sales function", but in many instances the system of ownership for sales orders may be manufacturing or resource planning based. Transactional order-based data is critical for the next step of the order to cash process which is resource planning. While many of the order details (quantity, due date) are 'created' in the sales function, their main use is in the resource and production planning functions. The system of record for transactional sales related data is typically the resource planning system which will be reviewed in the data systems section. Since this data is created in one function and used in another, consistent data is necessary to ensure a common understanding of the demand implied by the order. Having data in one system coupled with a process for verifying achievable due dates is vital to customer satisfaction.

In some cases, customer part numbers are also used – part numbers from the customers own product definition system. In this case the transformation of sales orders with customer part numbers into required production of internal part numbers must be done. In general, a customer part number should be associated with an internal part number (if it is different) within the engineering system which owns part definition data. In some cases, two different customers may have inspection or tolerance differences that otherwise are the same internally defined part. The most effective practice is to create different internal part numbers for any change in design, process or inspection to avoid this issue.

It is important to note that there is also data which is not updated as frequently as transactional order data or as infrequently as some customer data – a typical example is any long term contract with a particular customer which may control pricing, re-order timing and requirements, volume, and product traceability.

Material Requirements Planning

Downstream of receiving a sales order, for a specific quantity of finished goods is the process of material requirements planning (MRP). The goal of this function is to calculate what material and labor and how much of it is needed to meet the requirements imposed by the customer sales orders. This is to ensure that the production process is optimized with respect to raw materials or labor.

This description highlights that the MRP function uses data from the sales function, such as order quantity and order due date. It also utilizes part defining data from the engineering function to determine what purchased components and raw materials are required from the sales order. The MRP function also requires data from the inventory management function to determine what quantity of parts is 'on hand' and what quantity is required to be ordered.

A typical system of ownership for the MRP function is either a standalone MRP software, or an enterprise resource planning (ERP) software which also contains other functions. To ensure accurate and complete demand for raw materials it is critical that engineering data and sales data be delivered to the MRP function in an integrated manner that ensures timeliness of the data delivery.

Manufacturing Scheduling

Once the appropriate materials required for production have been planned by the MRP function, the planning of actual production is required. Manufacturing scheduling is concerned with planning of the internal operations to produce the supply needed to meet the demand from the sales orders. Given that the necessary resources were planned in the MRP function, the required inputs for production should have an expected availability which determines when production can start.

The function of manufacturing scheduling is to produce the right parts at the right time given the required completion to meet sales order dates. The data required comes from sales (demand quantity and due date), MRP (required material and labor), and engineering (bill of materials). Additional data which is required is the part routing and process information. Scheduling manufacturing requires knowing what steps are required in the value-add process and a method to determine how long each step will take. The part router is a key piece of data required for manufacturing scheduling.

The data produced by a manufacturing scheduling system includes a list of work orders for production with internal due dates which allow the sales order due dates to be met as best as possible. While the MRP function ensures that resources exist to meet production needs, the scheduling function creates production work orders that plan when different activities will be done. The complexity of this calculation can vary from prioritizing operations at work centers based on work order release date (FIFO) or optimized scheduling which can move around activities to achieve various objectives (specific customer priority, overall on time delivery, etc.).

A typical system for manufacturing scheduling is often common with the resource planning (MRP) software because of the tight integration required between ordering raw materials and scheduling production. The coordination between resource planning and manufacturing scheduling will be elaborated in the discussion of systems which handle those functions.

Manufacturing Automation

Once the production planning and scheduling process has been complete, the quantities on each work order must be created. The 'decisions' made at this level of production are like manufacturing scheduling but on a reduced time scale. For example, a manufacturing scheduling decision might be deciding which work order should be run on Machine A first based on downstream activities and due dates. A comparable manufacturing automation level decision would be "is the current batch of parts done? If so, set up the next batch". Data required to make that decision is often generated and then used within the manufacturing automation function – feedback from sensors, specific work instructions for workers, specific processing limits on machines etc. However, a key consideration for the automation function is understanding what data is required to flow back into manufacturing scheduling, in order to optimize manufacturing cell utilization.

The current and historical state of the manufacturing floor is needed for both scheduling and cost accounting. Therefore, data which is created at the manufacturing automation level such as work order status, machine uptime data and labor tracking data must be sent to the scheduling and resource planning manufacturing functions.

Quality Management

The quality management function is a critical function for highly regulated industries such as Aerospace & Defense. The quality management function's role is to ensure both the quality compliance of shipped product and to serve as the system of record for the methods for confirming quality and conformance to industry or regulatory standards.

The data used by the quality function can be subdivided into quality policy, part or customer specific quality agreements, and lot or batch specific quality certificates and data. Quality policy information may exist in a non-quality specific document management system but at a minimum should have version control and a hierarchy from enterprise level quality policies to specific inspection and test procedures. It is intended to cover broad aspects of quality management that cover all the product line and means of production rather that those that are unique to specific parts or specific customers. Customer specific information is structural and controls specific inspection or sampling requirements which are imposed by a specific customer. Finally, lot or batch quality information is transactional and updated routinely – it contains both copies of conformance certificates and raw test data used to justify lot quality. The quality function therefore deals with both functional and transactional data. Associated data which must be used includes part number definition from engineering and customer information which may come from the sales function. Data 'generated' in the quality department and used elsewhere would include quality holds or NCR's which need to be shared with the order management function to prevent the shipment of lots of materials which are being held for quality reasons.

From a system support perspective, a quality management system may be a standalone software which has document management and customized quality query and analytics capabilities. Quality support is also often an integrated module with some ERP or PLM providers.

Warehousing and Inventory Management

The warehousing and inventory management function exists to ensure that the correct amount of both raw materials and purchased part are available when and where they are needed, to meet the production demands, previously entered by the sales department. The resource planning function generates into materials and labor requirements, based on orders. Turning materials requirements into material orders (purchase orders) also requires knowing current inventory and appropriate lead times so that the right resources are available at the right time in the right quantity. Inventory management may also utilize a safety stock value to generate orders based on inventory alone regardless of received sales orders.

The inventory management function is therefore tied very closely to resource planning and sales orders and forecasting. If it is handled separately from resource planning, then current inventory levels must be shared with the resource planning function. For this reason, the inventory management function is often handled by enterprise-level resource planning systems (i.e., ERP) which can automatically generate purchase orders to be approved by the supply chain

Finance

The financial function of the company in the “order-to-cash” process involves coordinating the external payments (payments to suppliers and from customers) and internal costing (how much value ‘accrued’ to product as it moves through the operation).

The alignment between the financial representation of the flows of goods and money, and the actual movement is critical; sending payment for parts and adding parts to inventory, for example, is not the same activity, but a mismatch in timing or association can lead to missed payments or unexpected cash flow shortages.

For internal costing, much of the same information critical for manufacturing scheduling also underpins appropriately valuing finished goods inventory – what resources were used by each part or lot, and how many or how long was the resource utilized. Data which may be inherent to the financial function is the transformation of resource time into monetary value. This may require further classification of resources than is strictly required for planning purposes – for example there may be two machines which are identical from a scheduling perspective but have different cost structure. The financial valuation of the process and the resource planning and scheduling of the process itself are closely tied together.

Data which is created by the finance function includes associated part revenues, aggregated customer revenues, and average part costs (determined from resource costs and actual production history). This data may not be used directly by other functions but is frequently utilized for understanding the relative financial differences between parts. For instance, it may be desired to schedule work orders based on a customer priority list derived from customer revenue. Similarly, a sales customer relationship system may require pulling financial data to properly weight the importance of different customers. In many cases, the financial and resource planning systems are common systems to ensure the integration of these functions.

Order Management

The order management function is used to track and update the status and other related information for purchase orders, sales orders, work orders, and service orders. This function should be the repository for the status of any of these types of transactional data. This function may be distributed across and integrated into other functions. For example, the resource planning function may generate purchase orders with a required date which must then be maintained and shared with supply chain management functions. Alternatively, orders created in various functions (sales, resource planning, manufacturing scheduling) can be passed to a separate order management system. In addition to updating status and maintaining dates, order management functions also may be the source of record for shipping information for various service providers.

Definition and Scope of Data Systems

The functions required for the order to cash process each generate data and require data. The support of these functions can be accomplished through multiple data system approaches. One concept that becomes clear when reviewing the functions is that certain functions are more interrelated than others. For these functions, it is usually more effective and efficient if they are be handled within one system. The following section discusses the data systems that support these functions, with specific detail on different data systems which have overlapping functionality.

Product Data Management vs Product Lifecycle Management

The terms Product Data Management (PDM) and Product Lifecycle Management (PLM) are often used interchangeably. However, these two things differ in that PDM is a subset of PLM. PDM deals with structured management of product data while PLM covers PDM as well as change management, requirements management, some aspects of quality management and extends from product concept through product field support and ultimately obsolescence. PLM and PDM are both enabled by software solutions though the concepts of both are process based ideas. The software is essential in that it helps to more effectively and efficiently manage the data and makes searching and reporting more readily available. One thing to note is that PDM/PLM is often thought of as the domain of Engineering, though in properly deployed systems the data is used and is useful to numerous organizations throughout the business. In fact, in the OEM business it could be argued that it is essential that a cross-functional team be involved once the design progresses to the detailed design phase. At this point design decision ought to be influenced by manufacturing (both fabrication and assembly), quality, and program management in the case of complex products that integrate into other complex products (for example aircraft engines used on specific airframes).

The precise details of what aspects of PDM/PLM are deployed is tightly tied to the nature of the business. For example, OEMs will often manage from product concept and then throughout the entire lifecycle. While make to print or MRO shops often use/manage other people’s product data, only for the duration of the relationship with the OEM. Therefore, make to print shops can often scale back to a PDM solution as opposed to a full up PLM solution. The make to print shop has the responsibility to use and protect the OEMs data but play very little part if/any in the design phase of the product they are asked to manufacture.

When does PDM become PLM?

PDM was a natural outgrowth of Computer Aided Design systems. As such it primarily emphasizes management of CAD models, drawings and specifications. For many companies this is adequate, though for those who develop products and change them over time the added element of Change and Configuration Management is often useful, and in some case essential. Once Change management is injected into the process, especially with a formalized process involving cross functional groups, PDM starts to morph towards PLM. In a PLM system, all data and documents that support a design and specifications used in manufacture are associated to product through part numbers and Bills of Material (BOM). Typically, in PLM systems the BOM is referred to as the Engineering BOM or more usually the EBOM. Certainly, once companies make the decision to manage the entire lifecycle of their product definition in a formalized manner, PDM is in the rearview mirror and PLM is in play. Figure 22 below shows a conceptual graphic of the processes covered by a PLM throughout the life of the product and which areas are covered by PDM alone.

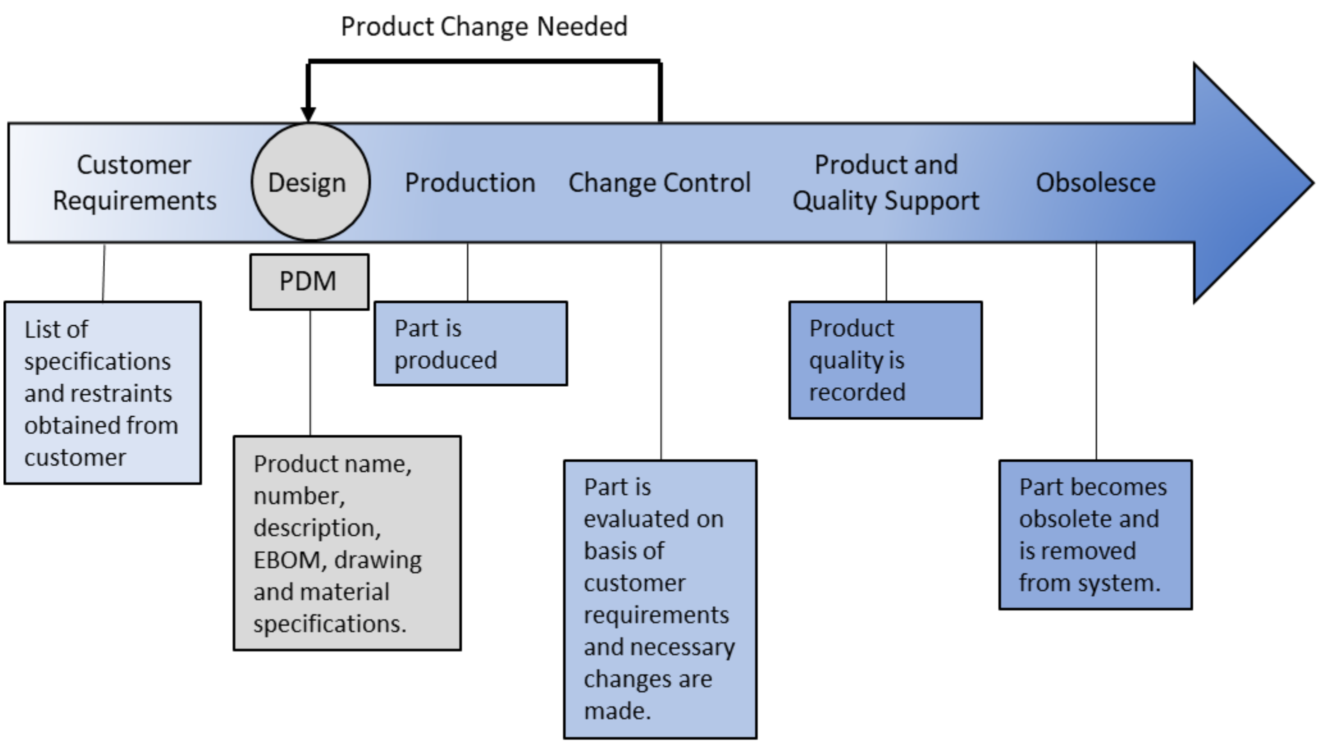


Figure 2: PLM Process

Engineering Bill of Material (EBOM) as the Basis for Understanding/Managing Product

The EBOM defines all the parts needed for a specific configuration of the product and defines the hierarchal relationship of part to parent from lowest level detail through sub-assembly and eventually in a recursive manner up to the delivered part number of the salable product. In situations in which the product is a complex multi-level BOM it is not unusual to also sell sub-assemblies and components as spare parts. The PLM system typically identifies which sub-components can be offered as spare parts and the system flags those parts as having potential for being sold as spares. The actual decision to sell a part or not is more of an economic decision made by spares organization but Engineering will define salability from a technical point of view. For example, a welded sub assembly may be flagged as salable whereas the individual details contained within that assembly will probably not be flagged as salable.

The EBOM defines what is to be delivered, that is how has engineering designed the product, and while used downstream to make decisions in manufacturing, it is not typically identical to the manufacturing

BOM (MBOM). MBOMs, while often also defined in PLM systems are the basis for manufacturing planning, and as such it not uncommon to find the MBOM created in a Manufacturing Execution System (MES) rather than in the PLM system. However, in that case validation of the MBOM against the EBOM is essential. At this point we have identified a point of contact between Engineering and Manufacturing, regardless of how that connection is executed. In other words, manufacturing consumes the EBOM during planning, but may add other elements to the BOM to define more clearly how the product is to be made, transforming the EBOM to an MBOM. For example, an MBOM may call out the use of a specific lubricant used purely for purposes of assembly. While this is essential to a manufacturing plan, and safe assembly, it is not typically considered as part of the delivered product, nor is it part of the essential functioning of the product in the field. It may therefore not be defined in the EBOM. However, it is normal for all specifications required to manufacture the part to be associated to the part numbers in the product in the PLM system and therefore indirectly through the EBOM. Material and process specifications are usually in the domain of Engineering and are therefore typically managed by an Engineering Quality function whose responsibility it is to ensure that clear specifications are documented and controlled. As such, these are typically considered to be part of the product definition and are usually managed in the PDM/PLM system and made available to other consumers of that data.

CIMDATA defines PLM using the following three core concepts:

1. Universal, secure, managed access and use of product definition information
2. Maintaining the integrity of that product definition and related information throughout the life of the product or plant
3. Managing and maintaining business processes used to create, manage, disseminate, share, and use the information.

PDM Scope

Product Data Management (PDM) was originally the electronic means of storing and managing CAD and drawing data in a centralized repository. As it evolved it also became a means by which this product data could be represented in the hierarchy of an Engineering Bill of Material (EBOM) with direct associativity of the product design data to the assembly structure of the product. PDM by necessity then encompasses the following:

- Product/model name and number
    - Version control of product/model names with or without formal engineering change control is a central function of PDM. This allows everyone in the company to see the product defined in a single consistent manner that eliminates variability in how numbers and part/product names are represented. This centralization of product definition is the primary benefit of PDM. Maximum benefits of this centralization occur when other software systems like ERP, Quality and MES systems are integrated to the central PDM system and uses rather than recreates the data defined by engineering. In many PDM systems these are also often referred to as end items being the numbers that are at the very top of the product bill of material. Generally, part numbers lower in the BOM are

the ones that carry detailed product definition, though it is not unusual to see a system level drawing defining unique attributes of the product.

- Part number of individual detailed parts and assemblies
    - Product /model numbers are simply special type of part numbers and as such the description and benefits defined above are applicable to component parts and assemblies. It is at this level that detailed drawings and CAD models are often seen and managed. Again, in its simplest form this may be without formal change control and simply rely on versioning of the models and drawings. For greater control and error proofing it is most likely that some form of engineering change management occurs either as part of a broader PLM system of separately. If CM is done separately then the PDM system is manually updated to reflect the latest revision of a part number along with its associated drawings and CAD data. The real benefits of control of part number and models comes when PDM evolves into simple PLM and incorporates formal CM processes under control of electronic workflow. More about that later.
- Part description
    - Part description while seemingly obvious is most effective when some form of naming governance is applied. This means that an agreed upon naming convention is used. In most organizations this often follows the DoD standard which has a noun, qualifier construct. For example, "BOLT-Hex,1/4-10". Where Bolt is the standard part name and the rest simply adds further descriptions. The benefits of standardized name and standardized qualifiers is that searching, and reporting becomes much simpler. For example in a situation in which a quality issue surfaces on a part and we need to understand if that issue could possibly have occurred on other parts like it, we need standardized nouns to first find the total possible population and then use other meta data to narrow things down to understand the extent to which we may have similar issues elsewhere. While the bolt example is an issue that is typically easy to handle, one description that can be a problem is SLEEVE. Sometimes this is defined as a FERRULE. If the two terms are used interchangeably, which is fairly common, then it becomes difficult to differentiate a sleeve that is actually a metal tube crimped to secure wire that is used to hold a mechanical component versus a sleeve that may be of plastic material used to shrink wrap electrical wires. Clearly, differentiation then requires at least one additional filter to separate the two uses. The purpose of PDM and all the other system described here is to efficiently and effectively use data to make decisions as rapidly as possible, implying minimizing the number of steps and manual intervention. Data governance/definition is a critical part of enabling this goal.
- Engineering Bill of Material (EBOM)
    - Not all PDM systems implementations involve EBOMs. Many companies stop at managing the part number and its basic product data, the drawing and CAD model. Managing EBOMs usually involves taking the step of implementing formal change management and configuration control, but not always. Inclusion of the EBOM provides a foundation for communicating important product information downstream to both the

ERP and MES systems when deployed. If an EBOM is managed (with or without change control implemented directly in the PDM system) the entirety of the data needed to produce a product can be passed onto materials planning for example. Not only does engineering benefit from clear and concise understanding and management of product data but using the centralized PDM system as the system of record for the EBOM enables elimination of duplication of effort in other functional areas in which EBOM information is needed. One of the earliest ideas put forward in this paper is the idea of "define once and use many times". This is a prime example of that idea in practice.

- Unit of measure
    - For physical parts the unit of measure is typically each, whereas for bulk items such as paint or other chemicals the unit of measure varies depending on volume and typical means by which the material is supplied. Examples are kilogram, pound, gallon, liter etc.
- Schematic or CAD drawing
    - For physical parts it is typical to, as a minimum, manage a 2D dimensional drawing of the parts and for assemblies of parts a 3D drawing illustrating how the parts are assembled. Usually today this is accomplished using Computer Aided Design (CAD) software, though it is not uncommon to communicate with manufacturing engineering and /or suppliers by producing a 2D drawing. The 3D CAD model, should it exist, is also managed within the PDM system or sub-system of a full-blown PLM solution that has been deployed.
- Material and process specifications
    - Regardless of how a part is designed, material specifications are typically documents describing the constituent components of a material, limits on temperature, stress etc. Also, process specifications that describe such things as how material is welded, heat treated, coated or otherwise fabricated/produced, are generally managed in the PDM system and should be associated to the part by an associative reference.

A well-designed PDM system defines each data object uniquely, manages versioning of the data objects and establishes tight relationships of objects to ensure that for any given part, for example, that all other relevant data is tied to the part allowing for comprehensive and accurate product definition.

PLM Scope

Product Lifecycle Management (PLM) includes PDM but extends coverage of data from product concept/requirements, through development, detailed design, manufacturing, environmental compliance, export compliance, IP management, Maintenance and Overhaul and Repair to product obsolescence.

This lifecycle is supported by the following functions when deployed in its broadest possible form:

- Requirements definition/management/validation.
    - In businesses with complex products, particularly those that are highly regulated and/or involve delivery to Government agencies, it is common to have a disciplined requirements definition and management process. That is not to say other industries cannot benefit from this functionality but in Aerospace and Defense. For example,

product performance, cost, maintainability and other key product metrics are often specified by the customer and must be met according to strict contract agreements. In those situations, defining the requirements and deriving lower level component requirements that are required to support the product or system level requirements requires a disciplined approach to defining, mapping and verifying that all requirements are met. For simpler products this may be something that can be waived since requirements tend to be described in simple and therefore readily manageable terms. In these situations, it is not likely that a formal process of requirement management will be implemented.

- Advanced PDM (this includes all the scope of PDM described in the preceding section plus, model driven change directly from the revision of CAD models, and document management tied directly to the part numbers the document describes)
- Configuration and Engineering Change Management tied to EBOM management
    - US Department of Defense introduced the concept of CM in the 1950s. It was not until the 1960s that the benefits of CM were recognized and adopted by industry at large. As perhaps expected, the DoD formalized CM standards in the 1970 to allow greater emphasis on data/product management, quality control and interoperability. In 1980 CAD became available through Unigraphics, then a subsidiary of McDonnel Douglas. Dassault introduce Catia the following year. Through the 1980s CAD evolved to PDM and eventually to PLM. According to various sources American Motors Corp are recognized as the first adopters of PDM to develop the Grand Cherokee which they started to develop in 1985, and introduced in 1992, by which time AMC had been absorbed by Chrysler.
- Data exchange with suppliers and customers for purposes of manufacture and/or design collaboration.
    - When products are to be delivered to a customer in which the product is a significant part of the final product delivered to a customer it is typical to iterate on design and exchange data to ensure system level integration and interoperability of the product. For aircraft engines being delivered to meet the propulsion needs of an aircraft; the complexity of both the airframe and the engine demand that design interfaces between the two products be defined and checked during design of both products. This requires that data, including complete BOMs and CAD models be extracted and delivered to the customer for purposes of design verification. This can also be something that may be required to meet other needs of customers who need to check fit and function of component parts also, but the example of complex systems and sub-systems emphasizes an import aspect of data exchange. The PLM system keeps track of the latest revision of a product and as such functionality designed to choose, extract and package the models required is a natural fit into the PLM arsenal of tools. This can also prove valuable in situations in which an OEM is delivering data.
- New product development including:
    - Program management
    - Project management

    - Design
    - Validation
    - Transition to production
- Export control through tagging with appropriate ITAR and Commerce Department export classifications as well as access control and role assignment
    - In companies that collaborate outside the borders of their country of business it is often necessary to manage export of both technical data and commodities in accordance with the export laws of the country under whose jurisdiction the company operates. In the US, export is governed by both the Commerce Department and the Defense Department. Understanding the export classification applicable to the object being searched is critical to lawful exchange of data as well as export of finished products. It has now become common to see these classification values associated with the data objects as meta-data to ensure universal visibility of export controls for the object. This must be part of a large-scale training exercise to ensure users can properly interpret and respond to the classification.
- IP Control through access control and role assignment.
    - In companies in which non-employees are granted access to the data systems it is advisable to flag and control objects that are considered intellectual property requiring protection. Unlike export controls, which are no-negotiable, government-imposed regulations, IP control is at the discretion of senior executive and owners of the company. IP control is also completely un-necessary if non-employees are not allowed free rein in the data systems.
- Environmental compliance through identification of materials of concern and the ability to report in compliance with various international environmental laws.
    - It is becoming increasingly important to be able to report on the use of material of concern defined under various environmental compliance rules in Europe and Asia. The PLM system can be used as the basis for defining the amount of the product that either contains or was manufactured using material of concern. In the future, regulations will require complete reporting of such materials for imports into certain countries.
- Interface with ERP and/or MES systems to ensure engineering product data is accurately represented.
    - The PDM/PLM system can supply master data to all downstream business systems and should do so to conform to the rule "*define once and use many times*". The interface could be as simple as a bolt on program that is triggered to grab data that is packaged and delivered to servers that can be accessed by the downstream systems, with reciprocal programs to receive and upload the data. Conversely, it could be an integrated third-party tool that has been developed through collaboration between the PDM/PLM vendor and the vendor of the downstream system. It is essential for some form of data exchange to take place to eliminate duplication of data.
- Manage CAD data ensuring various analytical data is also associated directly to the design it is meant to analyze.

    - Some companies find it convenient and effective to capture various forms of Computer Aided analysis results within the PLM system. This tends to be something large manufacturers with complex products are starting to implement. While not without value for small and medium sized companies the cost of deployment versus return on investment (ROI) may make this a little harder to justify. It certainly would not be the first part of PLM that any company would deploy.
- Electronic Workflow (WF) to help define and support the process of change.
    - WF that defines and supports a formal process within the company can have tremendous value for control of data, conformity to standardized processes and ultimately as a means of measuring process cycle times. One of the most common WF applications seen in PLM implementations is that of engineering change management. The value of EC control through WF comes from ensuring that all company functions impacted by a change are engaged in the approval process and can influence timing to ensure that all necessary steps are taken to smoothly implement the change. While small and medium sized companies may consider this redundant, because "people communicate" with one another and because they perceive WF to slow down the process, it does in fact ensure that no one is surprised by decisions.
- Design for manufacture and/or assembly.
    - It is not uncommon to hear horror stories of engineering decisions that cannot be supported by manufacturing. Unless design for manufacture/assembly is ingrained in the engineering culture there is a reliance on engineers making designs that not only can be made but can be made as effectively and efficiently as possible. This is not typically a skillset that designers possess and as such using design for manufacturing/assembly functions can help improve this aspect of design. If manufacturing planning and production supervision are involved through WF that alone is a vast improvement over isolated engineering design decisions, but design for manufacture as a formalized process can step this up to yet another level.
- Manufacturing Planning and Execution
    - Some PLM systems now offer the ability to model shop floor layout, machining tool path simulation, automation simulation as part of a manufacturing planning function. In addition, these systems now also include scheduling and routing capability as well as data automation. This blurring of the lines between traditional PDM/PLM functions and MES functions makes decisions on choice of systems somewhat more complicated. It is important when considering this type of PLM centric system to understand to what extent the advanced simulation of the shop floor and individual operations yields value. These PLM centric MES systems leverage the integration with CAD, allowing 3D modeling of equipment and floor space for advanced analysis of manufacturing operations. While this can be very useful it may exceed the needs of some companies with well-established manufacturing facilities.

These capabilities also help support engineering's role in assessment of quality non-conformances as well as design in context of customer products and in the company's own products when the product is highly complex and involving multiple design teams.

It should be noted that not all companies require all these capabilities. The companies most commonly employing all or most of these capabilities are Aerospace and Defense OEMS of major vehicle and propulsion systems.

Resource Planning and Production Systems Overview

The following section defines the scope, data types managed, and history of resource planning and production systems. These systems (ERP, MES & MRP) are grouped together as they have a common historical development and related, though differing, functionality. They all try to address universal questions related to production – "what do we have to make and how much, and what do we have to buy and how much?" With regards to the functional definitions introduced earlier, the various resource planning systems cover at a minimum the resource planning function. However, as this section will show, many other functions are supported by these systems which all grew out of resource planning. Later sections will discuss in detail the typical borders between these systems and how they differ from one another.

Enterprise Resource Planning

Enterprise resource planning, or ERP, is a type of enterprise system (ES). In contrast to legacy systems, enterprise systems span across typical functional departments within the enterprise. Enterprise systems eliminate the need for multiple, possibly disconnected or loosely coupled, departmental systems and reduces the time required for communicating across these systems as well as the risks associated with maintaining data in multiple data systems. ERP is an enterprise system that supports core functions of the business – procuring primary inputs of materials and labor, tracking the value-adding process, and holding data required for accurate distribution and sales. More specifically, ERP moves beyond the basic matching of demand and supply to add cross-functional integration to support production planning, finance, sales/distribution, quality management, customer relationship management, inventory management, and in some cases quality management. ERP software houses the required data for these activities in one central interface and data base. However, since engineering defines product definition, the source of some of that data comes from a tightly integrated connection to a PLM system.

The scope of an ERP system spans the enterprise level of a company crossing all business functions. In doing so it also supports management of production and the factory floor. While they vary in breadth and sophistication of module support, an ERP system, at a minimum, provides data for the enterprise level administrative and accounting activity of the business. An ERP system is responsible for everything that manages the flow of materials and financial information. The potential breadth of a typical ERP system is one part of its appeal. Many providers offer a multi-module approach that allows customization of the total amount of integrated activity.

The data types that would be defined within an ERP are a mix of structural and transactional data. The historical base function, materials resource planning, generates transactional demand for resources to support production. The manufacturing scheduling function (often also supported by ERP) requires structural data such as definitions of work centers and part routers. Significant datasets that would be used by ERP but defined elsewhere include part defining data and sales orders (if not integrated with the ERP).

Manufacturing Execution Systems

Manufacturing Execution Systems, or MES, are used to track and manage manufactured goods on a production floor. This can be both component part fabrication and assembly operations. A MES manages the production in the factory by having the granularity and real-time data required to model the production process to a high level of accuracy. An MES uses data from the product definition and customer orders and adds the production status and work center capacity to create a plan to produce the goods in a low-cost, time and space efficient way. MES planning can resolve tasks measured in minutes as well as those that may require hours to execute. By doing so they can estimate when work orders will be complete and available for the next operation.

The general scope of an MES system is focused on production management of the factory floor, however an MES will communicate with ERP systems and can overlap responsibilities if required. MES software generally deal with a product from order to delivery, but do not manage anything outside the direct lifecycle of the product in its production. For example, an MES will properly estimate when a work order will be complete using real-time available capacity but is less likely to automatically create an invoice once the work order is complete, as an ERP system might. The ownership and differentiation of tasks between ERP and MES will be expanded upon in a later section.

As with the ERP system, an MES will define both structural and transactional data which is updated frequently. The dispatch, or status of work orders by station and quantity, could be updated multiple times a day. Structural data such as work center definition, while not fixed, is updated less frequently.

History

The general history of manufacturing systems is tied closely to the evolution and constant improvement of computing power. Development of computers lead to the introduction of software applications for the most data rich and documented function at the time, which was accounting. Automated accounting software quickly led to material requirement planning (MRP) systems in the late 1960’s which helped lay the groundwork for MES and ERP systems. MRP consisted of a master schedule, bill of material, and inventory records which it used to calculate what materials were required to meet demand. The first generally accepted use of MRP was in support of the Polaris program. Then in 1964 Black and Decker became the first company to adopt MRP.

Production data acquisition (PDA) and machine data acquisition (MDA) which were developed in the late 1970’s enabled the MRP system to grow beyond an automated re-ordering system. This additional data from the production floor allowed the MRP system to know when parts would be expected to be completed compared with customer due dates based on the actual state of product on the floor. In addition to adding priority planning by linking the production floor, the next phase of MRP (known as Closed Loop MRP) also added functionality for rough-cut capacity planning, aggregation of sales and forecasting (sales planning) and customer order promising (demand management).

Closed Loop MRP would eventually lead to Manufacturing Resource Planning or MRP II which had the notable inclusion of Sales and Operations Planning, Simulation to test what-if scenarios, and a Financial Interface to translate the operating plan into financial terms. Most recently, the evolution of MRP II into ERP marks the broadening of functional scope that occurred as ERP programs became more developed and widespread. Added functions include supply chain management capability and a full financial integration.

While MRP was adding shop floor feedback and additional adjacent functionality to become the modern ERP system, systems which were more focused on detailed production management were also being developed. By the early 1990's these applications, which allowed for more frequent data collection and scheduling, became known as MES. The term was first used in 1992 by AMR Research, which is now part of the Gartner group. The Manufacturing Enterprise Solutions Association (MESA) came into existence in 1992 as well.

The main driver in the development from Material Requirements Planning to Enterprise Resource Planning and Manufacturing Execution Systems was the development computing power and the availability of data with which to automate manual processes or enable new analysis. Figure 33 below highlights some key milestones in the development of MRP, ERP and MES, and Figure 44 shows the capability that has added as MRP grew into a modern ERP system.

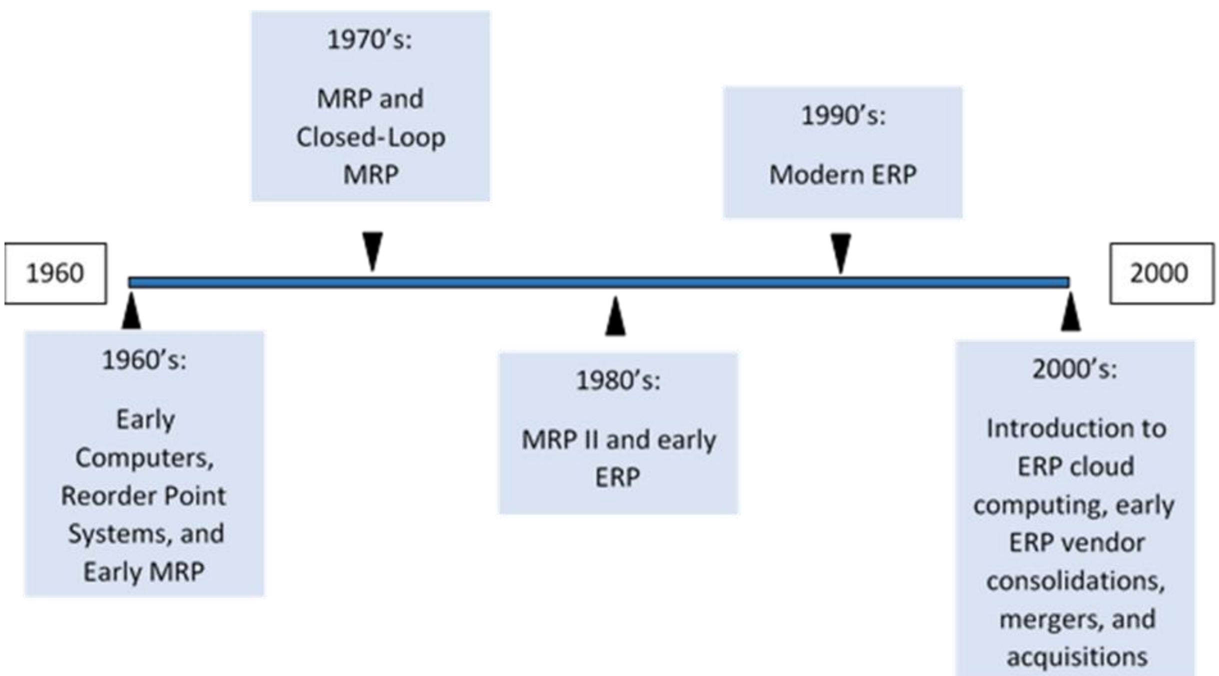


Figure 3: Timeline of ERP development

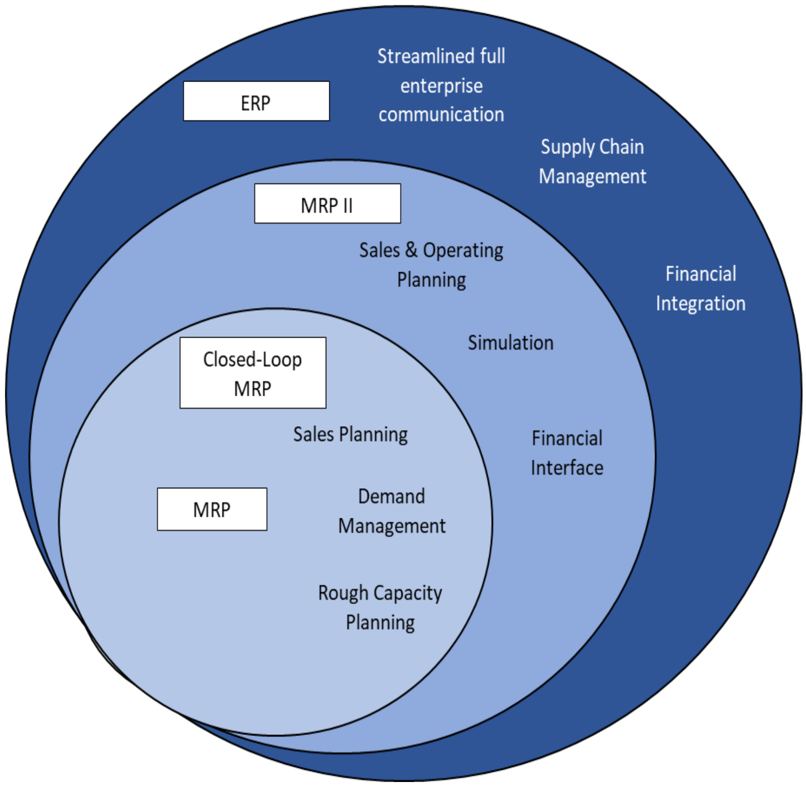


Figure 4: Visualization of ERP Historical Development

ISA 95

In comparing the offerings of an ERP and MES system, there can be significant overlap in the resource planning and production scheduling function. Understanding the typical boundaries between ERP and MES can be aided by a conceptual approach codified in the ANSI/ISA 95 standard referenced in the introduction. ISA S95 outlines five different levels of a manufacturing operations and states what is expected to occur inside of them. Level 0 is known as the production process level, level 1 is where sensing & manipulating occur, and level 2 is monitoring and supervising. Levels 0-2 fall under the umbrella of "Production Control and Automation". The fourth level, level 3, is the production management level, this is where MES systems operate. The final level is known as the Enterprise Scheduling and Management level and is the level that ERP takes place on. Level 4 is made up of enterprise management tasks supporting other business functions such as sales, human resources and finance. **Figure 5**5 below shows a schematic of the functional responsibility occurring at each level and the relevant timescales for the "decisions" that are made at that level.

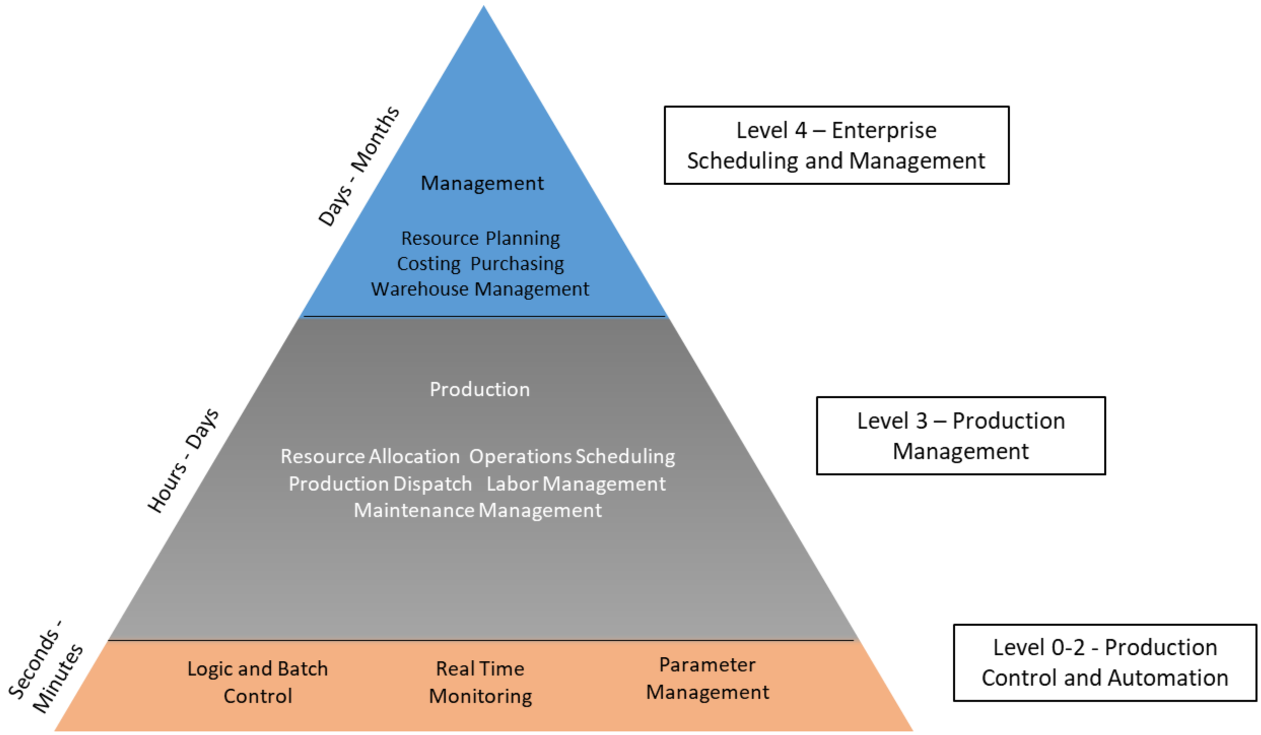


Figure 5: ISA 95 Schematic

ISA S95 dictates an ERP's duties as:

- "Management and maintenance of raw materials and replacement parts. Provision of master data for the purchase of raw materials and replacement parts.
- Management and maintenance of energy resources
- Management and maintenance of master data needed for preventive and foreseeable maintenance work and management and maintenance of personal master data for human resources department
- Adopting a rough plan for production and revising the plan based on the resources available and scheduled maintenance work
- Maintenance of warehouse master data
- Determining optimal stocks, energy supplies, replacement part stocks, and stock in production. This also includes examining material availability regarding order release production (Meyer)"

ISA 95 defines an MES's duties as:

- "Evaluation of production-relevant data, including determining real production costs.
- Management and maintenance of data related to production, inventory, personnel, raw materials, replacement parts, and energy. Furthermore, the management and maintenance of all additional personnel information/functions, such as timekeeping, holiday calendar, human resources planning, qualifications of employees, etc.
- Establishment and optimization of fine planning for every division. This also includes any possible maintenance, transport times, and all other production-relevant tasks.

- Reservation of resources relevant to orders (facilities, staff, material, etc.). Any changes (e.g., machine breakdown) should be recorded promptly so that plans can be altered, if necessary/ Data must be archived. The production orders are transmitted to the resources available by the system. They are redistributed automatically in the case of any disruption.
- General process monitoring functions (alarm management, tracking, tracing, etc.).
- Provision of functions for quality, management, compiling key figures, timekeeping, and maintenance management. (Meyer)"

Comparison of ERP vs MES

The main difference between an ERP and an MES system is the scope of the tasks that they perform and the data that the systems are responsible for managing. An ERP system oversees the enterprise level of a business where it manages how money and goods flow between suppliers and customers as well as transactional data which is required by other functions of the business. On the other hand, an MES system is responsible for tracking and monitoring the development and production of goods on the factory floor form order arrival to completion. In a basic sense an ERP tracks the financial and material data required for production while an MES tracks and manages the detailed operations that add value to the part. While it is not uncommon for ERP/MES software packages to include assets that overlap into the other's realm of responsibility, it is important to keep in mind the core purpose and scope. Another difference between an MES and ERP is the cost of the software that is used to implement it into the business. Since an ERP software covers a broader field of tasks it is usually made up of a larger portfolio of packages, it has a higher price than an MES software would have. A key capability that an ERP software performs better than an MES is the ability to account for rapid growth in business. An ERP system is better suited to assisting in a rapid business growth situation because it has the processes to deal with new customers and supplier product increase, as well as the human resource features to deal with new employees hired, already in the software portfolio. A factor in implementing either ERP or MES software will always be the amount of IT resources the company has available. An ERP software is more complicated so it will require more training, money and personnel to assure its success than an MES. Figure 5 shows the overlap of responsibility that occurs in typical ERP and MES systems and what each how each system covers things unrelated to their overlap.

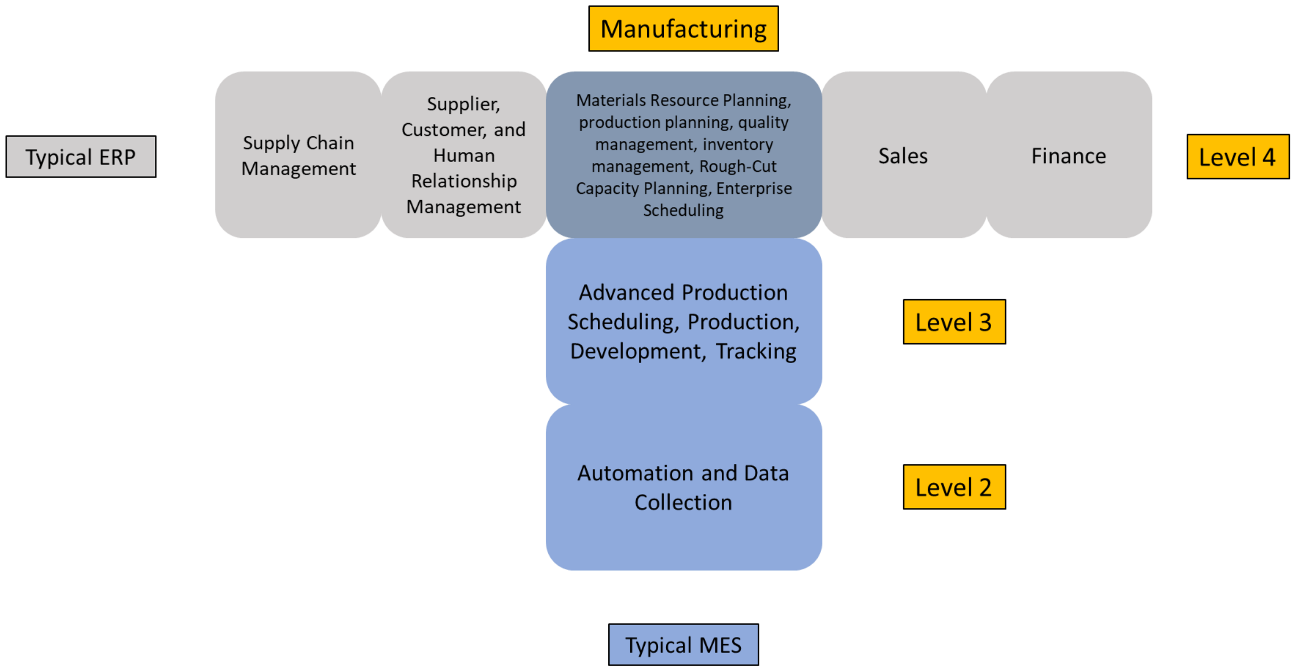


Figure 6: Typical ERP vs Typical MES

Data Transfer Across Systems

As discussed in the ERP and MES section, data transfer between the ISA standard production levels can be frequent and volumes can be high. In general, the speed and amount of data that is created or owned in one level and required in another level is a standard way to determine what functions should be integrated within one system. Another factor is if the data flow is bi-directional. Figure 7 below shows the planning, execution and control levels of production and data flows between them, as well as the supporting data from the PDM or PLM. This figure does show that the PLM sends data to both planning and execution to highlight that the ownership of the data is the PLM system. In practice it may be that the PLM only interfaces at an enterprise planning level which then sends that data to execution. However, in an MES centric approach, the PLM can send part number and EBOM information directly to an execution level system.

What becomes clear is that the volume of data and bi-directional flow of data between planning and execution indicates why ERP providers have looked to grow into advanced scheduling and execution and why MES providers have attempted to add more inventory, sales and finance integration. These functions are so related that it can be arduous to have distinct software systems for each.

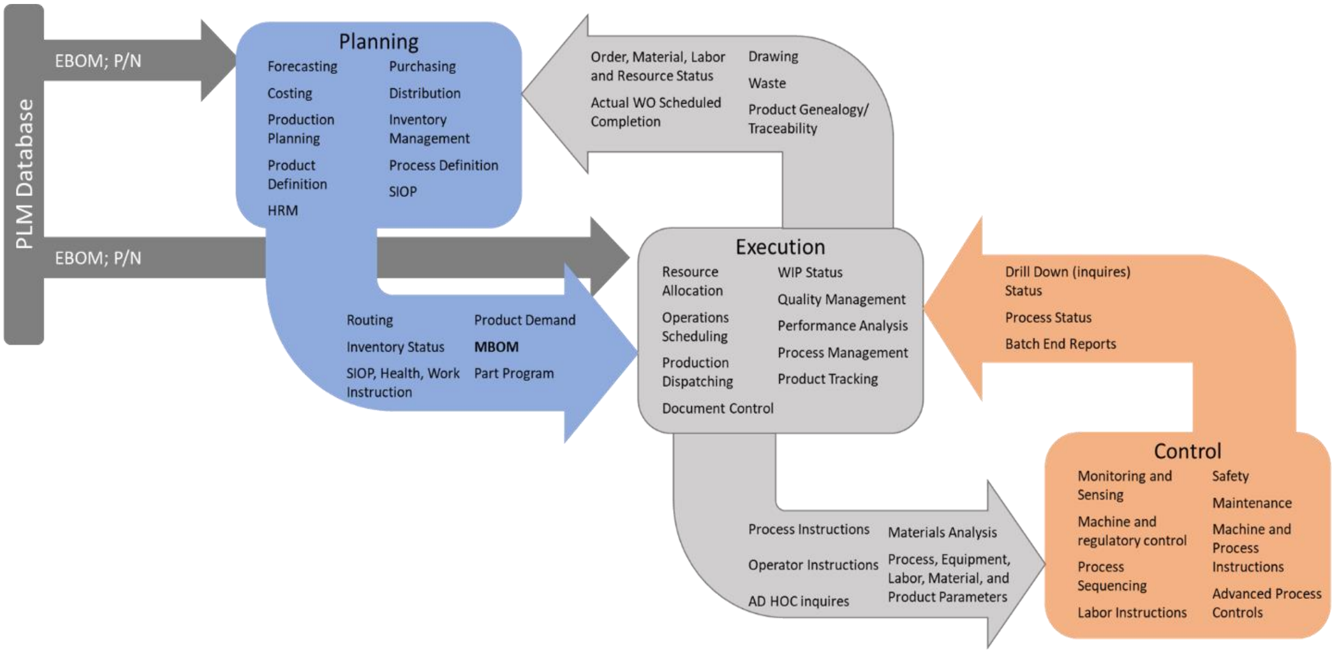


Figure 7: Relationship to PLM to Planning, Execution and Control System

Implementation

Software Type Considerations

ERP vs MES Scale

As simple as it sounds, it is important to keep in mind precisely what a specific company needs from the software it is looking to acquire. The following questions outline what programs you will need in the software.

1. What part of my business do I want to impact?
    - A complete definition of the requirements helps answer this question.
2. What software do I already have?
    - If existing software is to be retained how will it be connected to the new system(s)?
3. How much am I willing to spend?
    - This is also coupled with a break-even analysis to understand financial effectiveness of the decision.
4. Do I have enough IT resources to implement a larger software system?
    - This may be offset by hiring someone to do the implementation.
5. What do I need to do to sustain support for the new software system?
6. How much will my company grow?
    - This is important in assessing the scalability of the chosen software system

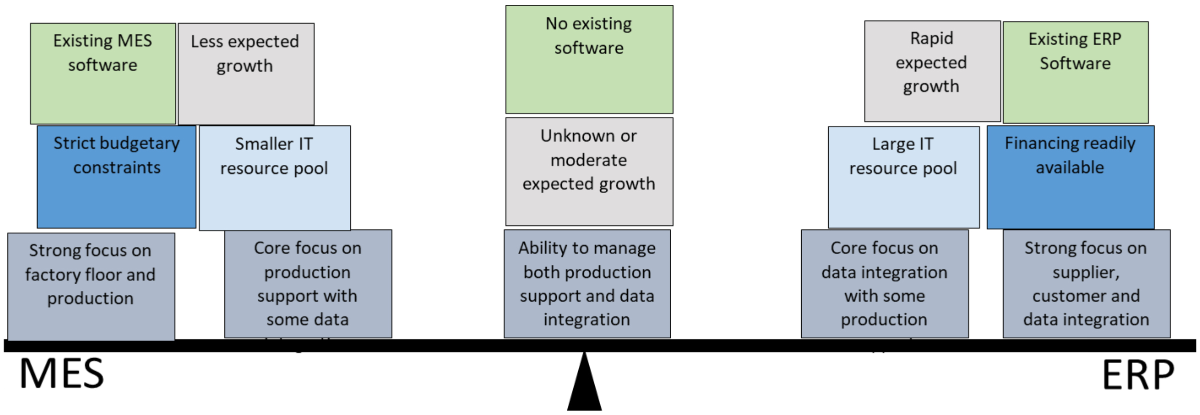


Figure 8: Scale Diagram of ERP vs MES Choice

In **Figure 8Figure 8** the questions that were posed to help narrow down on the exact needs of the company are represented with their possible answers to each with a weight to either side on the scale. It must be kept in mind that this level of weight and these specific properties of the options will not affect each company in the same way, but a similar thought process should remain. If the answers to the questions are mainly on one side of the center than the scale will "tip" in the favor of that decision. The weight on each of the block is characteristic of how much the "weight" of the answer tips the balance of the diagram. When considering if an MES software or an ERP software is the correct thing to buy it is important to realize that not all restrictions are as binding as others. Even if one system seems to be a perfect fit for a company there is an option to supplement what they are not getting with one from a company that will offer à la carte options or a package that fits a company's needs.

Cloud vs On-Premise

When looking for an ERP or MES software that is correct for implementing into a company, it is important to look at whether a cloud-based or an on-premise server should be used. A cloud-based ERP/MES is a piece of software offered as a Software as a Service (SaaS) by a vendor for a monthly price that is based online. An on-premise ERP/MES is a piece of software that is usually accompanied by hardware requirements. The software license is purchased from the vendor and installed locally at the company location. With this approach there is an initial investment for the purchase of licenses and an annual maintenance fee. Many large and well-known ERP/MES software providers offer both options and it is up to the company to pick the version they want to acquire. While they are the same software, each implementation has their own benefits and downsides.

Cloud

Some major benefits of using a cloud-based ERP/MES system are that the cost is a predictable monthly cost, it is a cheaper initial investment, and no additional hardware or IT team is needed to run it. Having a cheaper initial investment and monthly payments can help a smaller company jump the financial hurdle of introducing an ERP software. Another key benefit of implementing a cloud-based system is that updates and security for the system is handled by the vendor. Leaving security to the vendor reduces the need, or at least size, of local dedicated IT staff. One of the large benefits of a cloud-based system that is unique to it being on the cloud is that the system can be handled while traveling since it can be accessed on mobile devices and laptops, though VPN access also allows on premises software to be accessed remotely also. When comparing cloud-based services to their on-premise alternatives they often have less implementation time and better from the start performance.

The major downsides with a cloud-based system is that the company purchasing the system is not in charge of security, the system will be more expensive as time goes on because it is a subscription-type payment, compared to an initial investment (Figure 8), and the program will have reduced opportunity for company specific customization. The security risk is the biggest downside in a direct comparison to an on-premise software because it is more exposed for potential data breaches and security problems. Despite the lack of customization there are enough ERP/MES software vendors such that needs that are not filled by one provider may be covered in another program. Capacity of the vendor server can be a concern to a company if they are restricted to a specific amount of space they are given as additional space might draw an additional charge. A large downside with automatic updates and bugfixes from a cloud vendor is that forced updating can end up disrupting business if the interface changes and/or the program is down while updating. It should be noted that major updates can be complex, regardless of which architecture is chosen, and in either case careful planning will be needed.

On-Premise

The benefits of an on-premise ERP are that it is cheaper in the long run, data security is controlled by the company rather than vendor, the software is more adaptable to a company's needs and implementation is at the company's speed. The cost of an on-premise software will often be cheaper in the long run because its initial cost will be spread across the years of its use, whereas a SaaS will have a higher yearly recurring price (Figure 9). However, on-premise solutions still require yearly license maintenance fees and IT support costs to account for in the pricing trade-offs. Of course, initial deployment could be achieved using vendor resources to avoid the need to do all the work with full time company employees. This is a common model which then allows those resources to roll off the project after initial deployment, leaving daily support to local employees, or even contract employees in some cases.

In the modern era the main advantage to using an on-premise ERP/MES program is having data security and maintenance be performed by an in-house IT department as opposed to taking the risk of using the vendors security features. This is a larger advantage if the company looking to implement the software already has a competent IT and security system. It may also be necessary in some case when the new software is being connected to existing company software, because this often involves some level of customization to allow for the connectivity. If significant customization is desired there are considerations beyond whether the offering is on-premise vs cloud based. For example, the extent to which the software provides an application programming interface (API) impacts the feasibility and difficulty of customization.

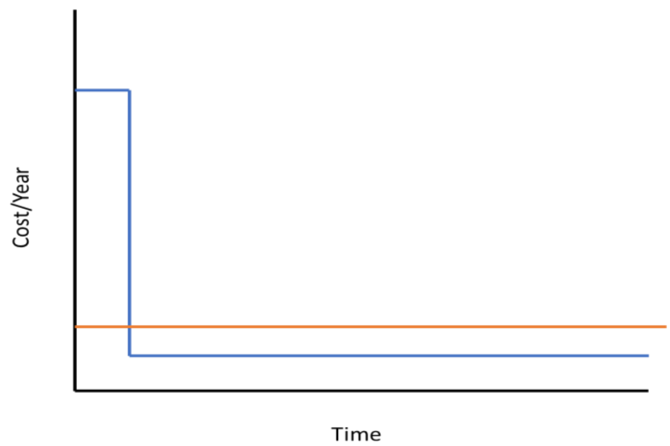


Figure 9: On-Premise Cost (Blue) vs Cloud (Orange) Over Time

The downsides of an on-premise ERP/MES solution include the risk associated with the upfront financial investment, increased IT and hardware costs, requirements of competent data security, a lack of support due to customization, and the long implementation that is associated with an offline solution. Many of these downsides are trivial for a large company but can affect a smaller company in a drastic way. For a larger company a large upfront cost is usually not a problem but for a smaller company finding the amount of liquid capital may be more difficult. Along with the initial financial investment, for a small company with little to no existing IT, the cost of adding IT and hardware may provide a substantial barrier that a cloud-based system may not.

Cloud-Based and On-Premise Comparison

In summary, it is generally better for a smaller company to go with a cloud-based ERP/MES rather than an on-premise system and vice versa for a larger company. The reason that a cloud-based software is attractive to a smaller company is that it never needs to be updated manually, it requires little to no initial investment, they do not have to worry about hiring or diverting IT personal to manage the security and problems with the system and it is a small bump to integrate into their business. Smaller business with unique needs for security and customization will be faced with a tradeoff between needs and one-time financial and overhead costs.

On the other hand, a large company can afford to divert the attention, funds, and personnel to make the ERP/MES software work well on premise for them in a way that will help their specific needs better than a cookie cutter cloud-based version will. However, the trajectory of the ERP software industry is heading towards cloud-based Software as a Service (SaaS) because of its adaptability and mobility. This may make support for on premise systems harder to find as the market shifts.

Cloud vs On-Premise Scale

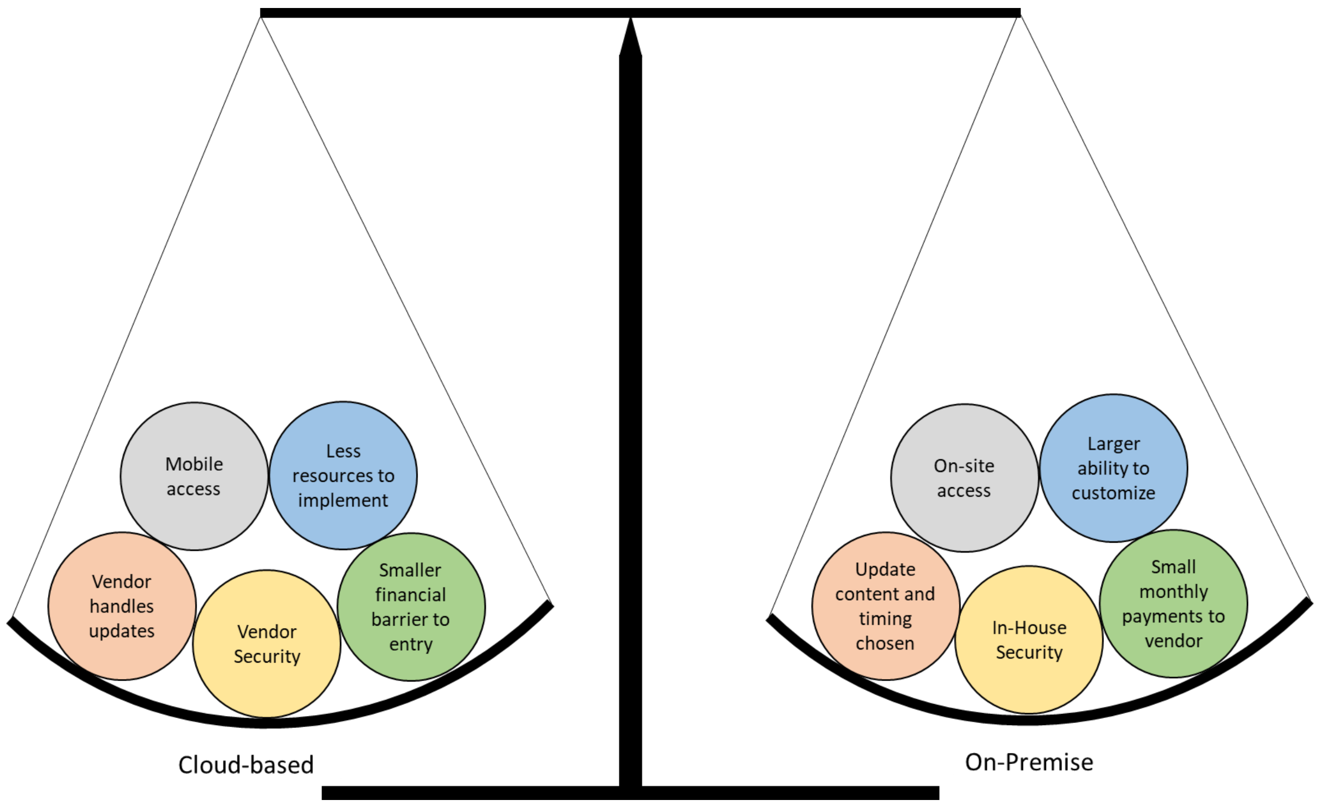


Figure 10: Cloud vs On-Premise Scale

Figure 10 describes the tradeoffs between a cloud and on-premise version of a software. The colors of each ball match up to a ball on the other side that represents the other side of a question. For example, in the yellow balls the responsibility of security of data is represented.

Other Considerations

Other factors that may impact the selection process include any current software and its compatibility. For example, both accounting and engineering design provide and require data from any ERP/MES software. However, they are less likely to be fully supported within any resource planning software. Therefore, the compatibility of any potential new software with any current software that is used and has a level of familiarity should be considered.

Company size is another factor which has some special considerations. While all companies look to minimize the cost associated with implementing a new data system, smaller companies in particular often have somewhat conflicting restrictions relative to larger companies; less ability to fund large implementation costs and less overhead (and relevant expertise) available to support that implementation. For small and medium sized companies, it is important to select a correctly sized solution – there are features that are offered that may not be necessary for a smaller, less operationally complex company – it is important that those non-required features aren't paid for.

Lastly, another software selection consideration for companies of all sizes is the risk associated with the vendor. Implementation is painful, obstructive and expensive. Choosing a vendor that can continue to be a solution for the enterprise is critical. The stability of the vendor, the customer support of the vendor and the track record especially in the relevant industry are all important factors.

Future of ERP and MES

The future of ERP and MES software is closely tied to the concepts and processes that the fourth industrial revolution have introduced. The major impacts from Industry 4.0 on ERP and MES will be artificial intelligence, machine learning, the internet of things, and a general decrease in reliance on humans. The integration of these concepts will lead to a new stage of ERP known as iERP (Intelligent ERP). Artificial intelligence can provide a massive boost to data analytics and predictive algorithms to help identify problems and advise a business on what action to take. AI in the form of a digital assistant can also help business to maneuver and learn about the software they use. Machine learning could provide an increase in the amount of quality data straight from the tools used by workers and will help an ERP/MES make better decisions and streamline repetitive tasks. Like machine learning and AI, IoT can provide an ERP/MES software faster communication, better organization, and coordinated management of time and resources. With a current MES or ERP software, a schedule for enterprise/production can be created, but IoT could help the plan go into effect through inter-machine communication without relying on humans to be on schedule. Another future outcome of Industry 4.0 in ERP/MES could be the decreased reliance on humans because of the automation of various tasks due to AI and IoT, this would free up humans to perform other tasks rather than manage the software.

Example Software

Example Software for ERP and MES software can be found in Appendix A and Appendix B respectively. It is important to note that these are examples not suggestions to use as your software, that decision belongs to you.

Top ERP and MES software

In appendix C is a matrix of ERP and MES software programs against a set of parameters designed to give a background on each of them.

The software analyzed in this matrix are:

- IQMS Enterprise IQ
- Epicor ERP
- Global Shop Solutions ERP
- Oracle Netsuite
- Infor Cloudsuite
- E2 Shop
- E2 Manufacturing
- SAP Business One (Light)
- Fishbowl Manufacturing
- Syspro Manufacturing Software

- Microsoft Dynamics 365 Business Cloud
- Plex Manufacturing Cloud
- Sage X3 ERP
- Mie Solutions Trak Pro
- Cetec ERP
- Genius ERP
- IFS Application 10
- Priority Software ERP
- QAD Adaptive ERP
- CAI Software ShopVue

The parameters used to evaluate the software are:

- When was the company established?
- Where are there headquarters? This is especially an issue if the servers are offshore because data housed offshore is deemed to have been exported from the US and may require special export controls.
- Approximately how many employees do they have?
- How many aerospace companies have they worked with (that can be found online)?
- Is the software MES or ERP centric?
- Was the software developed or acquired?
- Does it integrate with Solidworks well without third-party software?
- Is there an aerospace-specific version or compatibility in the software?
- What size of company is the software targeted to?
- Does the software have a manufacturing focus?
- What is the estimated price range?
- Website
- What platforms is the software on/compatible with?
- Does the software have an API that allows customization and/or data extraction?

Selection Process

The software selection process can be modeled in different ways, but at its simplest involves two tasks, defining requirements and evaluating vendors. Both activities are time intensive but necessary to ensure a thorough evaluation process. Defining requirements cannot be as simple as a list of everything that is desired. One approach is to use a two layered weighting to define requirements on a relative basis.

For example, to determine the requirements for functionality it is important to have users in multiple functions document the business processes they currently do (whether done inside a current system or not) and rate the criticality of that process being automated or supported in a future system. This weighting is then used so that the capability of a candidate software products can be scaled by the relative importance of that process, to obtain a weighted score to guide relative comparisons. In other words, the relative importance of functionality (vs usability, cost etc.) is used to apply a second layer of weighting.

In evaluating an ERP/MES software for example, the functionality, usability, technical alignment, vendor background, and cost would all be top level dimensions to evaluate against. Each dimension then will be decomposed into its contributing factors (such as business processes which define functionality). The rating of a candidate software's visual appeal, for example, would contribute to the overall score based on that factors weighting within usability, and on the weighting of usability relative to the other dimensions.

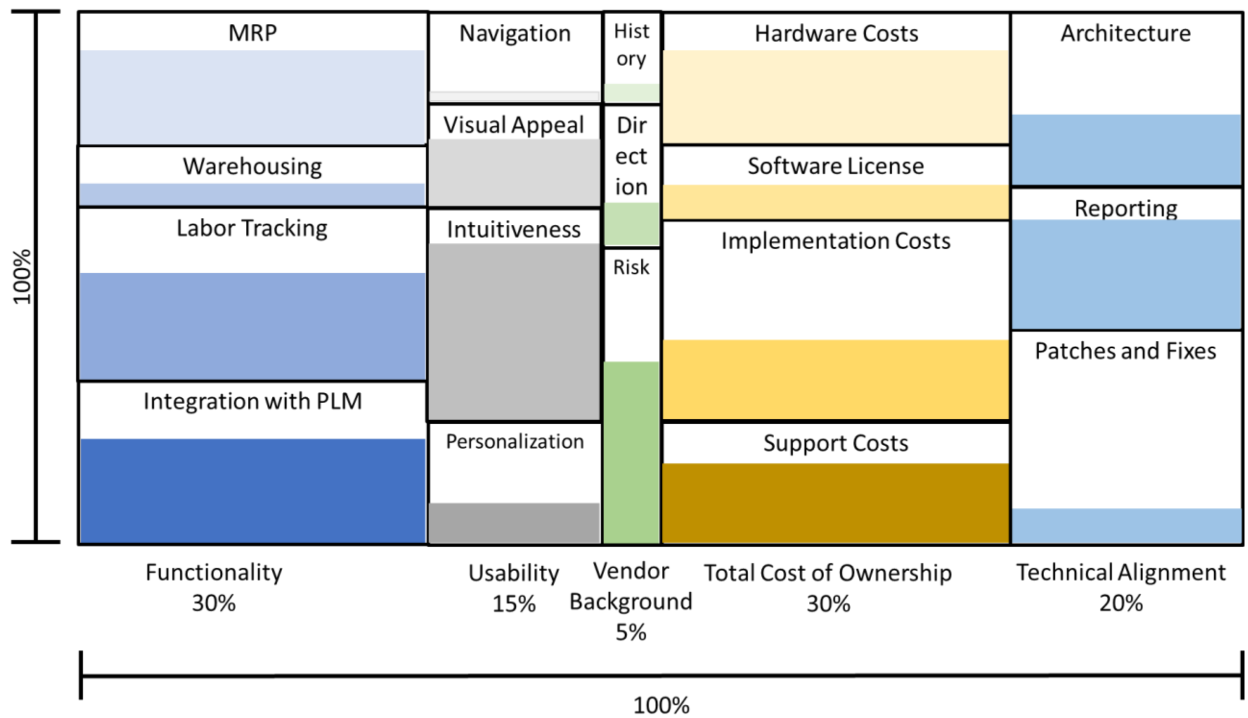


Figure 11: Example Visual Guide

In **Figure 11** an example visual guide of software selection is shown. The x-axis represents the different dimensions that the software is being evaluated on and the percent weight of the software's composite score. The y-axis depicts how much weight each factor is given of the category it belongs to. Each box has a score from 0 to 10, this score would be multiplied by the weight that it holds. For example, risk would fall under "Vendor Background" which has 5% of the total weight and has 50% of the weight in the category, this means the score for risk would make up 2.5% of the total composite. Risk's score is a 6 so its impact would be 0.15, the max score is 100.

While this is certainly not the only approach, whatever approach taken for defining requirements and evaluating software must be sure that some relative scoring is required (to ensure that the right requirements are prioritized) and that multiple users from each function are involved in selecting the ratings.

Appendix D contains a rough generic project plan for the software selection process. As a previous part of this project, an entire implementation timeline and step detail map was provided. Both give an insight into the interrelated activities that are part of the selection process.

Implementation risks

Despite all the positives that an ERP/MES brings there is always a factor of risk in their implementation. A risk a company takes in implementation is diverting a large amount of resources away from their regular business tasks to make sure the implementation goes smoothly. While it is critical that resources are devoted to implementation, it can often be counterproductive because if production falls behind and those personnel must re-focus on production this can cause implementation to fail. The best way to prevent this from happening is to have ERP/MES implementation occur as a secondary task to main production. Another risk exists if the upper management is not trained and fluent in how the software operates. This can limit the impact of an enterprise level system to an MRP type functionality if senior decision makers aren't using the information from the software to inform enterprise level decisions. For an ERP/MES to succeed at every level of the company, employees must be properly trained to understand their responsibilities, as well as how to query the software to support decision making.

A third risk exists if the ERP/MES software that is chosen to implement is not compatible with existing software. A way to avoid this from happening is to talk directly to the vendor and performing a demo of how your existing and prospective software work together. Overall the best way to prevent major problems with your software implementation is to educate every employee in the company on why and how the software works, to check with your software vendor about compatible software, and to make sure that ERP/MES implementation is not the main focus of your resources. After choosing a small number of candidate vendors and their software it is also necessary to ask for references to companies already using the software. Then a visit to that company or as a minimum a phone session with their deployment team will help get answers to questions that are usually impossible to obtain from the vendor themselves. Reference customers are more likely to be candid about issues they have faced with implementation and continued use. Vendors generally avoid those types of difficult conversations.

Appendix

Appendix A - ERP Software Example

It is important to note that this example is not a suggestion to use Epicor as your software, that decision belongs to you, this is simply an example of the scope and history of an ERP software.

An example of an ERP software that is on the market is Epicor ERP. Epicor is a global software provider that was founded in 1972 that provides industry-specific software for manufacturing, distribution, retail and service organizations. Their headquarters is in Austin, Texas but there are additional locations in Minnesota, Pennsylvania, California, Ohio, Georgia, and New York. Epicor has around 3,700 employees, 20,000 customers, and earns $800,000,000 in revenue. Epicor offers several off sprouts of their base ERP, which already focuses on manufacturing, to focus on industries such as; Aerospace & Defense, Automotive, Construction & Engineering, Discrete manufacturing, Medical Devices, etc.

While not very detailed or a view of everything they do, here is a list of what Epicor advertises their ERP software to be able to perform.

- Customer Relationship Management
- Global Business Management
- Planning and Scheduling
- Project Management
- Human Capital Management
- Business Intelligence and Analytics
- Financial Management
- Production Management
- Service and Asset Management
- Supply Chain Management
- Product Management
- Sales Management
- Governance Risk Compliance
- Business Architecture

For a complete visualization of what Epicor does is found in the graphic for Epicor below.

Epicor ERP

Deployment Choice—Cloud

Deployment Choice—On Premises

Human Capital Management

- Core HR
- Global HR
- Candidate Self-Service
- Employee Self-Service
- Talent Management
- Training and Development
- Position Control
- Timesheets

Service and Asset Management

- Service Management
- Returned Material Authorization
- Service Contract and Warranty Management
- Case Management
- Maintenance Management
- Field Service Automation

Production Management

- Job Management
- Advanced Production
- Kanban Lean Production
- Manufacturing Execution System
- Advanced MES (Epicor Mattec)
- Quality Management

Supply Chain Management

- Purchase Management
- Supplier Connect
- Supplier Relationship Management
- Inventory Management
- Advanced Material Management
- Manifesting and Freight Management
- Shipping and Receiving
- Warehouse Management

Planning and Scheduling

- Forecasting
- Master Production Scheduling
- Smart Demand Planning
- Material Requirements Planning
- Scheduling and Resource Management
- Advanced Planning and Scheduling
- Infinite, Finite, and Constraint-Based Scheduling

Financial Management

- Global Engines
- General Ledger
- Financial Planning
- Accounts Receivable
- Credit and Collections
- Accounts Payable
- Rebates
- Tax Connect
- Cash Management
- Asset Management
- Advanced Financial Reporting

Customer Relationship Management

- Contact Management
- Customer Connect
- Marketing Management
- Lead and Opportunity Management
- Case Management
- Mobile CRM
- Integration to Salesforce.com®

Sales Management

- Estimate and Quote Management
- Order Management
- EDI/Demand Management
- Point of Sale
- Commerce Connect
- Customer Connect

Product Management

- Bill of Materials
- Routings
- Engineering Change and Revision Control
- Document Management
- CAD Integration
- Product Lifecycle Management
- Product Costing
- Product Configuration

Project Management

- Project Planning and Analysis
- Project Generation
- Project Billing
- Resource Management
- Contract Management
- Planning Contract
- Time Management
- Expense Management

Business Intelligence and Analytics

- Operational Reports/Dashboards
- Descriptive Analytics (Business and Financial User Reporting/Dashboards)
- Diagnostic Analytics (Scorecards/KPIs, Financial Planning)
- Predictive Analytics (Forecasting)
- Data Warehousing
- Role-Based Analytics and Business Intelligence
- Mobile Business Intelligence

Global Business Management

- Multicompany Management
- Multicurrency Management
- Global Multisite Management
- Multilingual Data Management
- Master Data Management
- Scalable Deployment
- Global Engines

Governance, Risk, and Compliance

- Corporate Governance
- Risk Management
- Security Management
- Business Process Management
- Global Trade Compliance
- Electronic Compliance Reporting Tool
- Environmental and Energy Management

Business Architecture

- Cloud Deployment
- Microsoft® .NET and SQL Server® Optimization
- Enterprise Experience
- Web Access, Mobile Framework
- Enterprise Query and Application Search
- Business Process Management
- Social Collaboration Platform
- Enterprise Content Management
- Electronic Compliance Platform
- Security Management
- Service Architecture, RESTful Services
- Business Integration and Orchestration Platform

Appendix B – MES Software Example

It is important to note that this example is not a suggestion to use ShopVue as your software, that decision belongs to you, this is simply an example of the scope and history of a MES software.

An example of an MES software is CAI Software's ShopVue, a modular system for mid to enterprise sized discrete manufacturers. ShopVue was originally developed by Casco Development in 1984 but was acquired by CAI Software in 2018. ShopVue's headquarters are in Portland, Maine and has around 11-50 employees. ShopVue has targets the Aerospace & Defense, Automotive, and Medical Device industries.

Here is a summary of what they can do:

- Shop Floor Control
- Labor Management
- Machine Tracking
- Time and Attendance
- Lot Traceability
- Line Management
- Overall Equipment Effectiveness
- Paperless Manufacturing
- Productivity Tracking
- Quality Management
- Scrap Reporting
- Data Collection
- Traceability and Genealogy
- Digital Instructions
- Smart Factory

The ShopVue Modular MES Platform

• Auxiliary Modules : Not sequentially dependent. Per seat pricing. + Add On Fixed fee

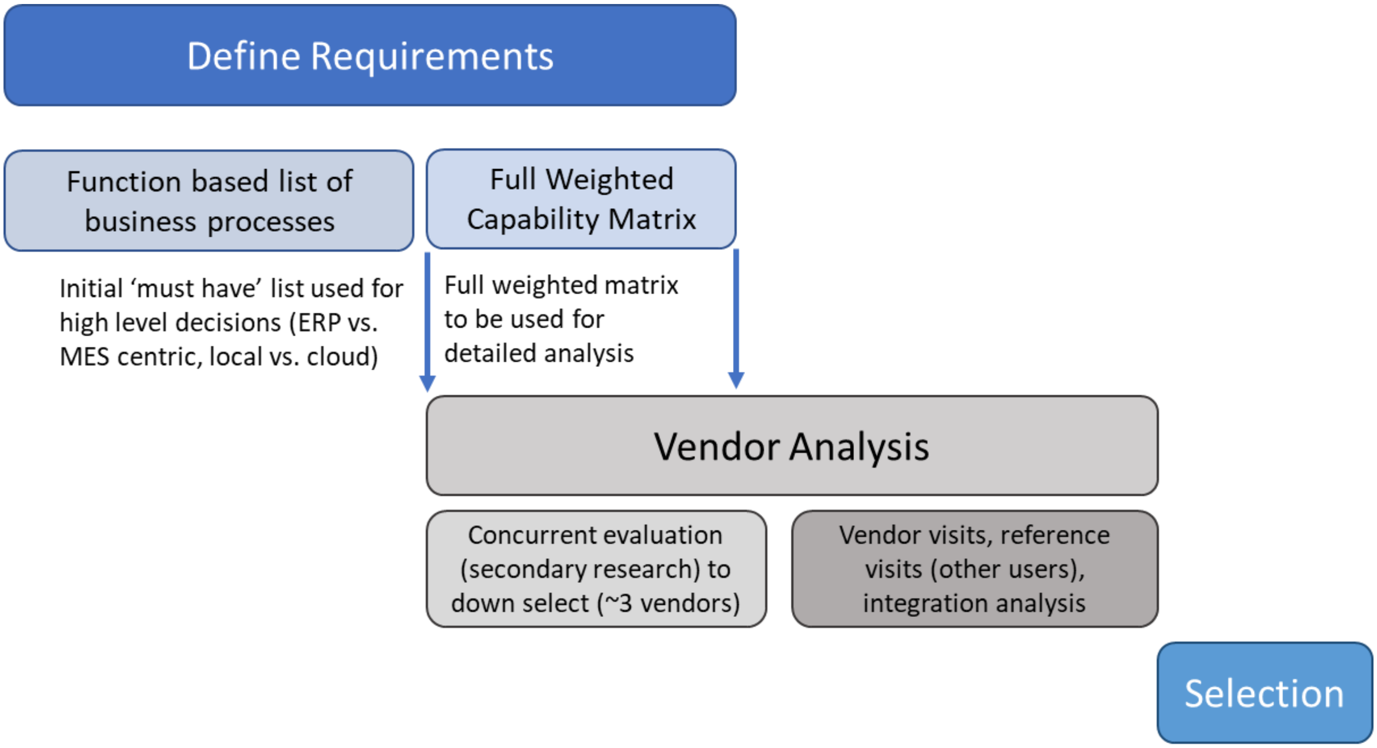
Appendix C – Top ERP/MES Matrix

Company	Software Name	Established	Headquarters	Size (Est)	Aerospace Penetration	MES Centric
IQMS	Enterprise IQ	1989	Paso Robles, CA	312	Unknown	Offers Version
Epicor	ERP for Manufacturing	1972	Austin, TX	3,700	High	Offers Version
Global Shop Solutions	Global Shop Solutions	1976	The Woodlands, TX	292	High	No
Oracle	Netsuite ERP	1998(Acq 2016)	Redwood Shores, CA	5,350	Unknown	No
Infor	Cloudsuite Aerospace ar	2000	New York, NY	17,000	Unknown	No
E2	Manufacturing system	1984	Hartford, CT	246	Some	Yes
E2	Shop system	1984	Hartford, CT	246	Some	Yes
SAP	Business One	1972	Newtown Square, PA	100,330	Unknown	Offers Version
Fishbowl	Fishbowl Aerospace and	2001	Orem, UT	175	Some	Yes
Syspro	Aerospace Manufacturin	1978	Costa Mesa, CA	1,325	Some	No
Microsoft	Dynamics 365 Business C	1975	Redmond, WA	158,503	High	No
Plex	Manufacturing Cloud	2001	Troy, MI	570	Moderate	No
Sage	X3 ERP	1981	Atlanta, GA	13,660	Unknown	No
Mie Solutions	Trak Pro	2007	Garden Grove, CA	34	Moderate to Low	Yes
Cetec	Cetec ERP	1996	Austin, TX	13	Some	No
Genius	Genius ERP	1989	Longueuil, QC, Canada	76	Low	No
IFS	Application 10	1983	Linkoping, Sweden	3,700	High	No
Priority	Priority Software ERP	1986	Rockaway, NJ	132	Moderate to Low	No
QAD	Adaptive ERP	1979	Santa Barbara, CA	1,950	Low	No
Cai	ShopVue	1978	Portland, ME	422	At least one	Yes

Company	ERP Centric	Developed or Acqui	Solidworks without third party	Aerospace Designated	Size range	Manufacturing focus
IQMS	Offers Version	Developed	Yes	Yes	S/M/L	Yes
Epicor	Offers Version	Developed	No	Yes	S/M/L	Yes
Global Shop Solutions	Yes	Developed	Yes	Yes	S/M	Yes
Oracle	Yes	Acquired	No	No	S/M	No
Infor	Yes	Developed	No	Yes	S/M/L	Yes
E2	No	Developed	No	No	S/M	Yes
E2	No	Developed	No	No	S/M	Yes
SAP	Offers Version	Acquired	No	No	S/M	Yes
Fishbowl	No	Developed	Yes	Yes	S/M/L	Yes
Syspro	Yes	Developed	No	Yes	S/M/L	Yes
Microsoft	Yes	Acquired	No	Yes	M/L	Yes
Plex	Yes	Developed	No	Yes	S/M	Yes
Sage	Yes	Acquired	No	No	S/M	Yes
Mie Solutions	No	Developed	Yes	Yes	S/M	Yes
Cetec	Yes	Developed	Yes	Yes	S/M	Yes
Genius	Yes	Developed	Yes	No	S/M	Yes
IFS	Yes	Developed	Yes	Yes	S/M/L	Yes
Priority	Yes	Developed	No	No	S/M	Yes
QAD	Yes	Acquired	No	No	S/M	Yes
Cai	No	Developed	No	Yes	S/M/L	Yes

Company	Price Range (Estimate)	Website	Platforms
IQMS	$25K+	https://www.iqms.com/	Cloud-Based (Saas), MS SQL Server, ODBC Compliant, Oracle, Amazon Web services (Cloud)
Epicor	$4K -500K	https://www.epicor.com/en-u	Cloud-Based (Saas), MS SQL Server
Global Shop Solutions	$5K-500K	https://www.globalshopsolut	Cloud-Based (Saas), MS SQL Server, ODBC Compliant
Oracle	$10K-100K	https://www.netsuite.com/pr	Cloud-Based (Saas), IBM DB2, IBM UniData/UniVerse, MS SQL Server, MS SQL Express, MS Acces
Infor	$25K-500K	https://www.infor.com/indus	Cloud-Based (Saas), MS SQL Server
E2	$7,000+-$250,000	https://www.shoptech.com/e	MS SQL Server, Premise
E2	$5K-200K	https://www.shoptech.com/e	Cloud-Based (Saas), MS SQL Server, MS SQL Express
SAP	$25K -$250K	https://www.sap.com/produc	IBM DB2, MS SQL Server, Oracle, Progress, Proprietary, Premise
Fishbowl	$5k+	https://www.fishbowlinvento	Cloud-Based (SaaS), Premise, Quickbooks, SQL
Syspro	$25K-500K	https://us.syspro.com/industi	Cloud-Based (Saas), MS SQL Server, Other, Universally Compatible w/all Data Base Platforms, Pre
Microsoft	$8K-$250K	https://dynamics.microsoft.cc	Cloud-Based (Saas), MS SQL Server, MS SQL Express, MS Access, Microsoft Azure
Plex	$50K -500K per year	https://www.plex.com/indus	Cloud-Based (Saas)
Sage	Unknown	https://www.sage.com/en-us	Cloud-Based (Saas), MS SQL Server, Oracle
Mie Solutions	$ 5K-$ 500K	https://www.mie-solutions.co	MS SQL Server, Amazon Web services (Cloud)
Cetec	40/user/month	https://cetecerp.com/	Cloud-Based (Saas), MySQL
Genius	$3000-$4000	https://www.geniuserp.com/	Cloud-Based (Saas), MS SQL Server
IFS	$300K-2M	https://www.ifs.com/us/indu	Cloud-Based (Saas), Oracle, MySQL
Priority	$1,400-$3,000/license	https://www.priority-softwar	MS SQL Server, MS SQL Express, Oracle
QAD	Unknown	https://www.qad.com/	Unknown
Cai	Unknown	https://shopvue.caisoft.com/	On premise

Appendix D – Selection Process Diagram



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