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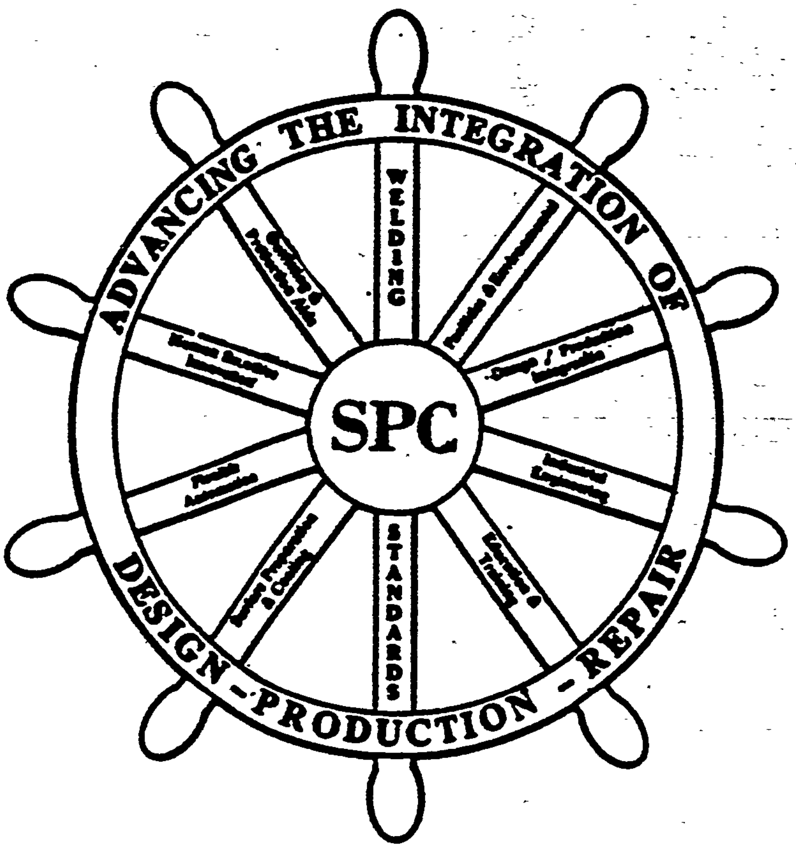

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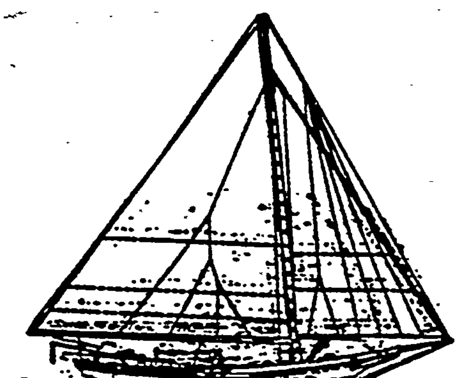

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Formal Manufacturing Approaches to Modern Shipbuilding

No. 1OB

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ABSTRACT

This paper describes how a formal manufacturing environment, as defined by the American Production & Inventory Control Society (APICS), compares to modern shipbuilding techniques. Formal manufacturing, through a product based build strategy, provides a framework for integrating contract scheduling, design development, material purchasing, inventory control, production capacity planning and production control. An understanding of formal manufacturing provides a foundation for understanding modern shipbuilding techniques.

INTRODUCTION

Shipbuilding is the physical transformation of material into a product that has value to a customer. In short, shipbuilding is manufacturing. In the authors' experience, however, the comparison between shipyards and other manufacturing businesses is down played. Manufacturing is often associated with products such as toasters, not at all comparable with a warship. Therefore, the body of knowledge associated with manufacturing management, Production and Inventory Management (PIM), is not generally applied to shipbuilding. This conclusion is typically based on two notions: ships are products which are much too complex and PIM is only applicable to identical products produced in great number.

There are differences between shipbuilding and other manufacturers, but they are of a more subtle nature. Many of the problems shipbuilders face are like those of any other manufacturing business. For example, people who order material for their operation (either purchased or fabricated) have limited knowledge of when it is needed, exactly how much is needed or both. Their experience is that the system is unreliable, so it pays to keep a few extra on hand. As a result they tend to order more, earlier, Just-In-Case.

Meanwhile the people who fabricate the items like to build a lot of them. This seems to be the most efficient way to manufacture things, particularly if performance is based on manhour utilization. They never seem, however, to have enough room to store anything, so both the shop floor and storage areas are always clogged with material. In spite of the mountains of inventory, expeditors are often looking for something that is missing and needed right away. It might not have been made or it might be lost. The one person who knows for sure is usually on vacation.

These universal problems of manufacturing are the ones addressed by the practitioners of PIM, often with great success [1,2]. As a result many of the concepts of PIM are applicable to shipbuilding and merit study. One of the best sources of information on manufacturing management is the American Production and Inventory Control Society (APICS). This paper will introduce some of these concepts and compare them with modern shipbuilding techniques.

Formal Manufacturing

PIM starts by viewing manufacturing as a process which requires a control system. Like any control system, PIM requires the classic elements of planning, execution and control [3]. Planning is the process of goal selection and the development of steps to achieve the goal; execution carries out the steps, while control measures the results so that corrections may be fed back into the plan.

The planning process in manufacturing is a complex one ranging from capital acquisition decisions to which hole John Doe should drill before lunch. Yet all planning functions must answer the four questions basic to any manufacturing business (shipbuilding

Included). The question suggested by Wight are [4]

> What are we going to make? (And **when?)**
>
> **What does it take to make it?**
>
> What do we have?
>
> What do we need to get?

All manufacturing businesses must answer these questions yet they do not do it in the same ray. I" the informa1 manufacturing enviorment, planning **is** performed **in** a disjointed ad hoc manner. Often much **of** the planning is left up to the production people on the **"deckplates"** The only guidance they receive **from** upper management is to do **whatever** it is they do faster and with fewer resources. PIM concepts describe. on the other hand. the forma1 manufacturing environment. Among its characteristic is that the planning process is we11 defined, coordinated from top to bottom and results in we11 defined goals. Planning **is** often organized by the time frame the it covers: long, medium end short **[3]**

Long Range Planning. Long range planning operates in the context of corporate strategy and capital acquisition [5]. The answers to the four questions describe the very nature of the company. They state what the basic products are and what facilities and equipment are necessary to produce them. Planning at this level is done in aggregate units that are appropriate for the manufacturer. An auto maker plans the rate at which passenger cars will be made; so many thousands per year. A shipbuilder could state the rate that it will deliver certain classes of ship such as so many tankers per year. If the type of market cannot be readily predicted then the Production Plan (the PIM term for the rate which sets the overall level of manufacturing output) can be stated in more universal units such as man-hours.

Medium Range Planning. Medium range planning further defines the Production Plan. Now the rate of production is turned into an actual schedule for specific quantities of specific items [6]. The planning horizon is reduced to approximate the longest cumulative lead time of the products. Depending on the nature of the business this schedule, called the Master Production Schedule (MPS)[1], is set in anticipation of sales, or only in response to a specific customer order. The proverbial toaster manufacturer operates in a make-to-stock environment where, to be competitive, the customer never waits. Most American shipbuilders operate at the other end of the spectrum known as build-to-order where, in exchange for a custom built product, the customer waits through the entire design and manufacturing lead time.[2] Nonetheless, a schedule can be stated for the specific number and types of ships that will be delivered that year.

The MPS in a formal manufacturing environment is constrained by the Production Plan. A capacity analysis is performed against major facilities to insure that in aggregate the MPS is a feasible plan in line with the corporate goals [6].

One of the most important factors which distinguishes the formal from the informal manufacturing environment is the care with which the MPS is prepared. In the informal environment the MPS is often arbitrarily determined without consideration of its impact on all parts of the company such as Finance or Engineering. Further, the MPS is often set unrealistically high as many managers believe this acts as an incentive to drive production higher. When people realize that the MPS is unrealistic, it ceases to become a credible plan against which performance can be measured [7].

In the formal manufacturing environment the MPS is agreed upon by all divisions of the company as a realistic plan which achieves corporate goals. Then as conditions change the best trade off among goals can be made. For example, suppose Marketing has come up with a major potential sale. Based on the MPS, if the capacity for the new business is not available without seriously disrupting the plan then the new business might be turned away. An alternative would be to eliminate or delay some part of the old plan in favor of the new business. Another alternative could be arranging for increased capacity to handle both the original plan and the new business. This could be through extra shifts, subcontracting or overtime. In any case the MPS is not arbitrarily changed. Instead those responsible are required to make choices in a visible and consistent manner as constrained by capacity. This insures that all concerned parties can agree that the MPS is realistic, and that their performance can be measured against it [7].

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1 In PIM jargon the MPS is always set in anticipation of sales. We will use it in the general sense of a medium level schedule for end products.

2 In between is the assemble-to-order environment. Here a unique product is assembled out of combinations of standard items.

Short Range Planning. Once the Master Schedule is set the plan can be taken tO the lowest level, where day-to-day decisions are made. In formal manufacturing environment the short-range plan is defined through the lower level or interim products which make UP the end product on the MPS. These interim products can be accurately defined regardless. of whether the product is built 0nce or one million times [8]. While this definition can be complicated by subtle interactions between process end product, the basic criteria is easy. What material does the mechanic need to perform his or her task? This material may be purchased or fabricated; it might be production support material that never 1eaves the Job mite; it might be material for the original design. or for a change incorporated ten minutes ago. To the worker these distinctions are irre1evant; if he or she does not have the right material at the right time the job cannot be completed.

Not only is material quantity defined in the p1an but so is schedule. Once the due date is determined for the end product due dates can be determined for the interim products which support it through beck-scheduling. I" this manner a schedule based priority can be set for the production or purchase of each interim product. This is Dependent Demand, the idea that the need for one' interim product can be calculated based on the need for another [8].

The formal environment takes advantage of the product based plan to define and control the manufacturing process. Formal work authorizations are issued by schedule which direct that a specific quantity Of an interim Product is due 0n a specific date. The work authorization allows the picking Of specific amounts Of material to complete the job. In addition, process information recorded for each prOdUct can be provided with the work authorization. A complete package can be given to the mechanic with schedule, quantity, material definition and process all included [9].

Now that the forma1 plan is defined and execution authorized the loop can be closed by regular accurate status Of the work authorizations. If status indicates that completion will be late or quantity insufficient the information can be fed back into the plan Since all the interim products are linked together to show how they support the end product. status information can be analyzed to see how it affects other interim products. and potentially the end product itself.

The analysis may indicate that changes are necessary. These changes are transmitted by re-scheduling the work authorizations either earlier or later. This insure. that the mechanic is a1ways working on the product that has the highest priority; the one which must be worked now to support the plan.

With a formal product based plan. detailed capacity analysis can be performed. By associating the capacity consumed by a particular interim product with the schedule for its production. an accurate capacity profile is developed. If the rough capacity analysis has bee" performed Correctly at the higher levels the detailed plan will be achievable [3]. This is not to say that every day will be perfect. The dynamic nature of **manufacturing, guarantees day to day** problems. The higher level analysis, however. insures that the detailed plan Will be, on average, rea1istic over time.

Informal Manufacturing

All manufacturing firms perform these short range planning functions or else product would never be shipped. The differences among them can be defined by the different way these functions are performed.

The informal manufacturer typica11y Controls his interim products with little or no regard to dependent demand. In the make-to-stock world this means order points. When the on-hand quantity of an item drops below a certain point more are ordered, regardless of when they are actually needed based on the priorities derived from the Master Schedule.

The make-to-order manufacturer (like a shipbuilder) does not make 1arge batches of identical items. However. if there is no clear picture of individual priority. items are often grouped together for manufacturing efficiency even though their actua1 use may be apread out over wee or months. The orders are based on groupings thought to allow efficiencies in fabrication or ease of administration based on criteria like drawing organization (i.e., build all pipe piece. on thin drawing).

ONCE the order iS prepared, it is launched or "pushed" onto the shop floor based on the ear1iest need date for a few of the items. Because of the size of the order, large 1ead times begin to build UP as the entire order has to pees through any work center before the next large order can begin. For a typical JOb Shop operation, products spend about 90% Of their lead time in queue, waiting to be worked [7] This give. rise to the practice Of expediting. Based on current priority, some part of the Order may be needed right away. The expeditor identifies those items (because someone is asking for them) and "pulls" them ahead of the others. This practice quickly destroys the credibility Of any schedule as. the items without a champion now wait even longer. A worse situation occurs "hen there are too many expeditors. NOw a11 the products are the meet important an lmpossible situation As a result, planners often increased lead time. thinking that this will increase their chances Of getting their product on time. Instead, orders are queued even ear1ier making the backlog larger still. Lead times. increase and expeditors have to work even harder to break the log jam. This is because longer 1ead times mean less accurate orders. It is a simple rule Of forecasting: the longer the lead time of the prediction, the less accurate it will be. Now a vicious circle builds UP of lengthening lead times and increasing mistrust of the system [10] The shop knows that if it keep. to the schedule someone will try to accelerate the order based on immediate need. When they do accelerate the Order, most of it ends up being stored for weeks.

Building products ahead of need has other deleterious effects. They must be stored for longer periods incurring costs, and increasing the chances that the items will be lost or damaged. For Defense Contractors, there is the added risk that the product will become obsolete on the shelf as result of the continuous change required by the customer.

FORMAL MANUFACTURING MODELS

Formal manufacturing is a set of Concepts. As such it manifests itself in different ways when applied to different industries using different technologies. We would like to discuss three versions of formal manufacturing: MRP II, JIT/Kanban, and the management techniques presented by the National Shipbuilding Research Program (NSRP).

MRP II

one method used by formal manufacturers is Manufacturing Resource Planning (MRP II). This technique takes the elements Of the formal environment from the Master Schedule down through execution of the day to day plan and captures them on a computer. Figure 1 Shows a block diagram of the major elements Of MRP II. A note about terminology is in order. MRP II traces its roots to computerized inventory planning systems developed in the 1960's These systems, dealing only with inventory, were Known as Material Requirements Planning or MRP (often little MRP"). As these systems were integrated with other elements of formal manufacturing such as capacity and work authorization, they became known as Manufacturing. Resource planing (MRP II or "big MRP"). The inventory planning element Of these larger systems is Still called material Requirements Planning (little MRP) [11].

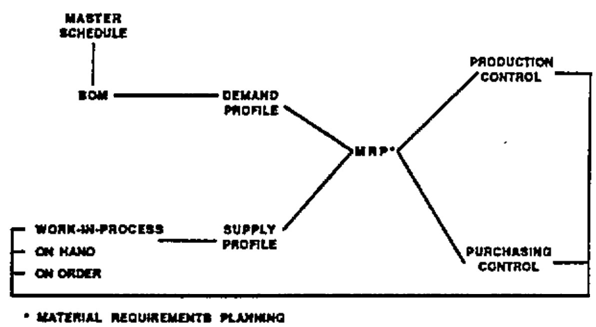

FIGURE 1
MRP II

Demand Profile. using MRP II, the Master Schedule is developed following the planning process already described. The definition Of the 1ower level interim products is captured in a bill of material (BOM). This. bill is not merely a list of material but Instead captures a serles of product and component relationships. It shows how raw stock and purchased components become interim products, which combine with other interim products (and more material) until finally the end product is reached. Figure 2 shows a simplified product structure for end item A. Here A is made up of fabricated items B and C and purchased item 1. Item B is in turn made up Of products D and E. This structure can be made as elaborate as necessary to represent the manufacturing process. The only requirement is that the interim products at any level be defined in terms of the interim products et the next 1ower level. This. definition is made strictly on the way the product goes together. It need not be besed on organization or other design constraints [8].

In addition to quantity, schedule can be associated with the interim products. The amount of time necessary to build or buy each item combined with the product structure allows back-sheduling. once the due date for the end item is determined (from the Master Schedule) , start and finish dates can be calculated for all the interim products which support it. This process can be easily envisioned by turning the product structure on its side and noting its resemblance to a schedule network [8].

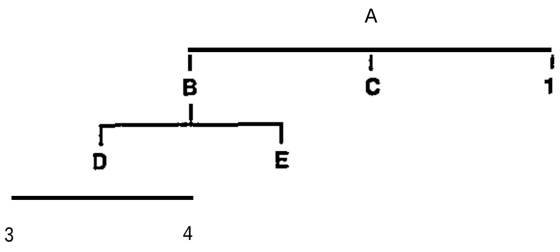

FIGURE2

STRUCTURED BILL OF MATERIAL

Collectively, the Master Schedule combined with the product structure form the Demand Profile on Figure 1. This is a time phesed view of the quantity of interim products needed to fulfill the Master Schedule.

Supply Profile. once an accurate Demand Profile has been calculated, it can be compared with existing inventory. The inventory records in the MRP II system contain both on-hand quantity and the schedule for receipt of committed purchase and nanufacturing orders. With this information it is relatively easy to calculate what additiona1 items are necessary to build or buy through time. This Supply Profile becomes the minimal plan to execute in support of the requirements captured in the Demand Profile.

The supply Profile is captured as a series of proposed orders. These are formal authorizations to either buy or build something. The manufacturing orders can be supplemented with process informataion, stored in the computer for each interim product.

Figure 3 shows a typica1 time phased inventory record contained in an MRP II syetem. Gross requirement show all known demand for the item across time based on the Demand Profile. Scheduled receipts show all known released orders to re-supply this item either purchase or manufacturing. The On Hand row indicates the levels of inventory that will be carried in each period based on the plan. Planned Releases represent the Supply Profile. the system's proposal for purchase or manufacturing orders that should be released to maintain sufficient inventory to cover the Demand Profile.

Feedback. The MRP II supply Profile can be modified to account for process or material constraints. For example, it may be desirable to build an item in multiples of twenty because that is the quantity which consumes an entire ber of rav stock. The formal system shows the demand this month to be for five only; the plan, however, may be adjusted to supply twenty for efficiency's sake. BY maintaining accurate status in the system, the fifteen extra items are known to be in inventory and available for future demands.

Building extra may sound suspiciously like the informal system. Suppose, however, that all has not gone well with the order. Perhaps the machine malfunctioned after making six parts and destroyed the remainder of the ber stock. Should a replecement bar be expedited? In an informal environment, the answer would probably be, yes, just In Case". someone might attempt to do research but it will probably be difficult to find out when or if the other fourteen are needed. With an MRP II syetem, however, accurate Demand Profile is available so the question can be readily answered. Thus, with MRP II, one has the option to combine small orders into bigger ones. The information on exact1y what is needed, is a1ways available.

Similar1y, other changes in order status will be reflected in the formal system. Information such as early or late performance as well as incorrect quantities bought or built is fed beck to the sustem. Then appropriate, frequent adjusttments can be made to the plan. This insures that work is being performed on the right product based on the most current information.

Feedback to the forma1 system allows the maintenance of both horizontal and vertical priorities. Vertical priority means that the priority of a product and the interim products which support it are linked. Thus, if item A (Figure 2) is re-scheduled by six weeks, the effect can be represented in the schedules for all the supporting interim products. This is an obvious result, though difficult to model on complicated products without a computer. More subtle, however, is the concept of horizonta1 priority. Here, if item D is unavoidably delayed, the priority for item E can be reduced as well. It is pointless to complete item E on time if it will end up in storage waiting for item D. This is particularly true if item E absorbs scarce capacity needed for another product with a new, higher priority. Accurate feedback of the formal system allows the situation to be recognized and appropriate action taken [8].

The Formal Manufacturer has learned that the key to managing capacity is to manage priority. In the informal environment, it is difficult to know

		1	2	3	4	5	6	7	8
GROSS REQS			20		25		15	12	
SCHED RECEIPT				30					
ON HAND	23	23	3	33	8	8	-7	-19	-19
PLANNED RELEASES			7	12					

LEAD TIME: 4

FIGURE 3

TIME PHASED INVENTORY RECORD

which job in the queue is the most important. As a result, capacity may be squandered by working on something that is not needed; now, or ever [12].

JIT

Other formal manufacturing systems have grown up without the heavy use of computers. Perhaps the best known is the Japanese Kanban system; an implementation of the principles collectively called Just In Time (JIT).

JIT is a formal manufacturing philosophy which strives to eliminate excess inventory in two ways. First, lot sizes are cut to the bare minimum. Traditionally, large lot sizes are justified by the economy of maintaining the setup over a number of items. Under JIT, careful attention is given to the factors controlling setup cost at workcenters. Second, products in the JIT environment are only built if they are needed at that particular time. Workers will be allowed to stand idle rather than produce items not immediately needed [14].

Kanban. Kanban embodies these principles into a simple card controlled system. As implemented at Toyota, there are two kinds of cards: a production card and a move card [14]. When the schedule says that an end item should be built, a worker starts to use parts from a full container to which a move card is attached. As soon as parts are used the move card is removed and taken back to the work center which produced the parts. There a full container is waiting with a production card attached. Now the move card may be attached to the full container and the production card removed. The move card authorizes transit of the full container to the next work station. The newly free production card authorizes production of exactly one container of the item. These containers are specifically designed to hold only a certain number (the authorized lot size) of the product. When this container is complete, the production card is attached to it. If no other loose cards exist, production stops at that work center. By regulating the number of cards and containers on the shop floor the system is completely controlled [14].

The Kanban system relies on repetitive manufacture of a few items. Even Toyota uses this system for only about 60-70% of their parts [13].

NSRP Model

We do not mean to imply that the shipbuilding industry has ignored the concepts of formal manufacturing. Over the last ten years, the National Shipbuilding Research Program (NSRP) has promoted the management concepts and techniques used by a number of overseas shipbuilders. These techniques represent an integrated, company wide approach to scheduling and controlling manufacturing through structured bills of material. Feedback mechanisms provide for the continual evaluation and refinement of strategy and execution. We highlight the match between NSRP concepts and formal manufacturing in greater detail in the following review.

What are we going to make? From a long term, or business planning perspective, shipyard organization and goals are centered around the measurement of value added [15]. This aspect of the strategic plan is best understood in terms of a make/buy analysis. The cost of "making" or internally generating a product is compared to the cost of purchasing that same product. This comparison is made strictly on a cash flow basis. Those products which can generate a sufficient rate of return, or value added, are designated as "make" [5]. For the shipyards studied by NSRP, the functions chosen as "make" are [15]:

- Design and component integration
- Assembly, installation and testing of finished components
- High volume fabrication, such as pipe piece manufacturing (where Group Technology can be applied to achieve efficiency)

Subcontracting is used to accomplish all other requirements; chiefly for low volume fabricated components. Beyond the value added criteria, subcontracting may also be used to minimize operating resources (i.e., to obtain special expertise or mitigate short term manning peaks) and to eliminate the drain on management resources required to keep a job shop environment running efficiently [15].

The beginning of product definition is material planning. Material planning establishes basic policies for classification, standardization, application, etc. These basic policies have three major goals;

- to improve the efficiency of the Production work force by minimizing the amount of learning required from project to project.
- to facilitate the design integration process by extending the applicability of previously developed design details.
- to minimize the number and type of truly unique items in inventory when multiple classes of vessels are working simultaneously.

The principal mechanism to achieve these goals is the standardization of products. Three types of standards are developed [15]:

- Vendor equipment standards, which provide a file of readily available engineering and design data without waiting for the negotiation and Purchase Order cycle to complete.
- Functional design standards, which detail common system, or sub-system characteristics using standard equipment.
- Detail design standards, which indicate assembly and fabricated component requirements for installation of standard sub-system modules.

Group technology plays an important role in the development of the shipyard standards. From Production's perspective, the experience resulting from building a unique item must be captured, and be applied across as broad a spectrum of similar problems as possible. Further, the amount of time required to shift from production of a given component to any other component inhibits the overall efficiency of the operation. Therefore, production standards seek to reuse past designs and process data, as well as provide guidance for new designs which minimize planning and set-up delays. This concept has been most highly developed in the piping area, where pipe pieces are grouped into families according to common processes (i.e., straight vs. bent) [16].

In keeping with the "assemble-to-order" philosophy, the shipyard seeks to eliminate purchasing lead times from the overall contract lead time. This is accomplished through long term agreements with vendors, which essentially reserve vendor capacity for expected shipyard purchases. These contracts generally specify target quantities for purchase, with price adjustments for over or under runs [15]. Changes in the market place (such as the surge in construction of clean product carriers in the late 1970's and early 1980's, which influenced the average diameter and total footage of pipe per hull), can have a significant impact on the bottom line for the company. Market analysis, is therefore, a key input to setting target quantities and adjusting bidding strategies.

<u>What does it take to make it?</u> Once a contract is signed, a two pronged strategy of design development is followed. The first is aimed at supporting early purchasing activities to ensure all required materials are ordered in time to support the production schedule. Of primary importance is the creation of the Budget Control List [17], a complete list of material by commodity used as the basis for projecting design, production and material costs. Initial purchasing actions; requests for quotes,

negotiations on price and placement of purchase orders is authorized by this list [15].

The Budget Control List is compiled from the Material List by System (MLS), which, along with system diagrams, is the principal product of functional design [17]. As each functional system matures, often using standard modules for sub-system layouts, the MLS documents the complete estimate of material required for purchase. Each item listed on an MLS is allocated to a material ordering zone (a temporary product used for scheduling purposes prior to detailed product definition) where it will eventually be installed. Particular emphasis is given to long lead items which are individually identified and listed with exact quantities whenever possible. Short lead items are frequently estimated only by weight within material cost codes [17].

Close vendor relations are an important aspect of the approach to purchasing. In many cases, the use of vendor materials as shipyard standards reduces the purchasing cycle. Continual contact with the vendors, required to maintain the shipyard's standards, also permits maintenance of pricing and shipping data. Purchasing decisions can be made rapidly from this file data, and purchase orders can be placed immediately. Further, vendor performance in both quality and schedule is enhanced when existing vendor products can be used [15].

The second prong of the design development strategy supports the refinement of the product definition through detail design. Detailed product definition evolves through a two step process; (1) Translation of the basic product line into specific products for a given vessel, and (2) Definition of each product through detailed design and materials information.

Using contract documents, functional drawings and early sketches from detail design, Production translates the basic product line into a detailed build strategy. As previously mentioned, the starting point for this translation is material planning and shipyard standards. The standards describe the basic building blocks of integration; functional service packages (or units in NSRP terms), or common structural block configurations for a given hull type. But these standards only provide a framework for the detailed product definition or build strategy required for each vessel.

As the design effort shifts to detail design, a series of meetings, referred to as "C" meetings, are held with the Production departments to aid in the development and communication of the detailed build strategy for each product [17]. The principal output of these meetings is a finalized pallet list for production. The pallet list forms the basis of a structured bill of material for the interim products of construction for the vessel. Each pallet represents a particular stage of construction for each product. It may be broken down simply by work center (on unit, on block, grand block, onboard), or may be broken down further by required work sequence (i.e., a pallet for each time a block is rotated to a new downhand position)[17].

Design develops for each pallet a Material List for Fittings (MLF), which details all the components for installation at a particular stage of construction. This list of components contains purchased items, subcontracted assemblies, items fabricated in-house (principally pipe pieces) and raw stock required for installation. The MLF is used to update material requirements from the original MLS, to budget and to control weight, and to kit material for the job site. The MLF defines the basic unit of work for scheduling and management purposes. For these reasons, the shipyards documented by NSRP consider the data systems for storing, sorting and collating MLFs as the most important systems in shipbuilding [15].

When the product definition has been standardized at a relatively high level, much of the design activity associated with defining the MLF can be focused on manufacturing problems. Reuse of previously developed technical analysis and design allows engineers and designers to devote time to manufacturing and producibility issues. Without existing details, technical staffs must spend significant amounts of time tracking down vendor data and accomplishing functional analysis. Time spent on these tasks tends to detract from producibility due to the pressures of schedule.

Each fabricated component shown on the MLFs, whether subcontracted or built in-house, is further supported by a detailed material list of the raw stock and purchased components required for fabrication. This is referred to as a Material List for Pipe (MLP) or a Material List for Component (MLC). When the detail design is complete, it is therefore possible to diagram a structured bill for the entire vessel, a somewhat simplified version of which is shown in Figure 4.

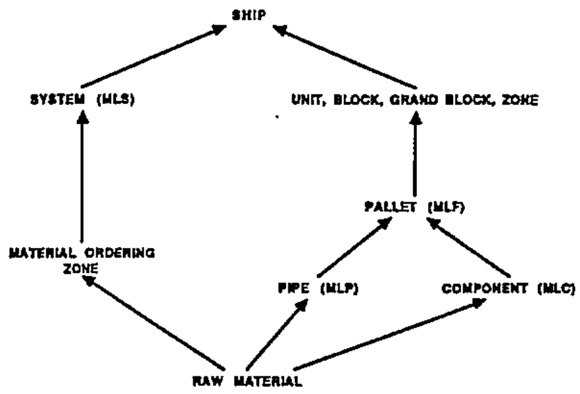

FIGURE 4
SIMPLIFIED BILL FOR VESSEL

When are we going to make it? Production scheduling is approached on the basis of the length of the horizon required for a given schedule. Shorter horizons allow increasing levels of detail in the schedule data [18]. In practice this results in a hierarchy of schedules; long, medium and short. It is also appropriate to think of this hierarchy of schedules in terms of the structured bill of material; construction products, pallets, and components. For long term purchasing schedules, developed prior to the availability of the pallet breakdown, individual construction products are aggregated into material ordering zones. Each item listed on an MLS is then allocated to the material ordering zone where it will eventually be installed. The use of material ordering zones allows for flexibility in adjusting product schedules by providing a way to relate material to the schedule prior to detailed palletizing. This facilitates the initial negotiations for component delivery, especially for long lead items. It is expected that as design and schedule data evolves to increased levels of detail (i.e., MLFs and MLPs/MLCs), material delivery dates will be refined to prevent both shortages and inventory surpluses.

What do we have, or need to get? Analysis of purchasing requirements is driven by a number of factors, including: owner requirements for unique items, item cost and lead time, surplus (if any), and the nature of long term purchasing agreements for common commodities. The material planning organization facilitates this analysis by classifying all items for purchase under the following scheme [15]:

- Allocated materials (A) - requires specific purchase by contract. Used especially for high dollar, long lead items.
- Stock materials (S) - required in high volumes across all contracts. Generally low cost items. Purchased based on historical supply vs. demand.
- Allocated Stock materials (AS)- standard materials whose expense justifies purchase against specific hulls. A single purchase order across contracts may be issued, but periodically supply is balanced with demand to ensure zero surplus relative to the backlog.

Inventory control specialists will recognize this as a classic implementation of an ABC, or in this case ACB, material classification scheme. ABC classification categorizes materials on the basis of risk (usually measured through annual dollar volume). It relies heavily on Pareto's Law: a small percentage of the items in inventory accounts for the largest fraction of value. For example, "A" items may be only 20% of the total items, but account for 80% of the total value of inventory. They, therefore, receive the greatest amount of management attention [19].

Figure 5, a representation of a Nishijima Ledger, illustrates the method for analyzing the supply vs. demand requirements of Allocated Stock materials. Quantities currently on-hand plus projected receipts during each time period are compared to total requirements for a given item. Deliveries are expedited to prevent shortages, and de-expedited to eliminate surpluses. In short, supply is balanced against demand. Comparison of Figures 5 and 3 highlights the similarity of this process to Material Requirements Planning.

Using the material lists developed by Design together with the schedule data prepared by Production, the Purchasing organization places all Allocated and Allocated Stock material on order for discrete delivery dates. This includes any subcontracted components which may fall into these categories. Due to the use of long term agreements, some components may already have purchase price and terms negotiated with only specific delivery dates required. As detail material lists are made available, A, and AS materials on order are checked against requirements to ensure accurate quantities are being purchased. As more detailed schedules are made available, delivery dates are

Economical Ord. Q'ty				Material Name		Standard No.		
Standard lead time								
Month		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.
Q'ty in Stock								
Q'ty Received								
Purch-asing	Q'ty							
	Requisition No.							
Q'ty to be used	Ship No.							
	" "							
	" "							
	Margin							
	Misc. Use							
	Sub-Total							
Q'ty used	Ship No.							
	" "							
	" "							
	Margin							
	Misc. Use							
	Sub-Total							

FIGURES

NISHIJIMA LEDGER FOR CONTROL
OF ALLOCATED STOCK MATERIAL

refined to maintain as close to just-in-time delivery as possible.

Approximately 30 days in advance of the scheduled delivery, responsibility for negotiation of delivery schedules with the vendor shifts from the buyers to the Production field expeditors responsible for scheduling pallets. This ensures that items arrive on-site precisely when needed, even though production shedules may shift slightly due to changing conditions on the Shop floor [15].

Additionally, for components fabricated in-house, the field expeditors may chose to subcontract as a means of level-loading fabrication facilities. Short term loading peaks are not handled by providing some additional capacity , or by Shifting work earlier than required. Rather, the peaks are simply eliminated by meeting delivery requirements through subcontracting. This reduces capital requirements for tooling and storage, as well as the costs of idle capacity.

Control and Feedback. Feedback in this approach is an absolute requirement. The constant refinement of delivery schedules to match shop floor schedules can only be achieved if procedures are in place to apply the changes in a timely manner. This is the chief reason for shifting negotiation of delivery to the field expeditors. Further, in multi-hull contrcts, production workers will inevitably discover required refinements to the detail build plan represented by the Grouping Of fittings within pallets. These refinements must be captured and fed back to Design. Typically this process is handled through a "D" meeting, held specifically to accomplish this review. The close scrutiny of both schedule and Plan is coordinated by a central group known as Production Control.

The Production Control organization is charged with coordinating all industrial operations through the integrated planning and scheduling of the entire shipyard. This

responsibility cannot be met without including control of material ordering and material stocks. In order to achieve the latter, the purchasing organization is part of Production Control. Basic responsibilities of Production Control include:

- General Control - Profit plan, operations plan, manhour allocations, scheduling and consolidated material planning.
- Purchasing - control of vendor and subcontractor relationships, procurement, value engineering delivery control.
- Expediting[3] - traditionel warehousing functions of recording receipt and issue. control of 5 and AS inventories, material kitting (palletizing) and transportation, and control of scrap and surplus. Control of delivery within 30 days of scheduled production.

Production Control, therefore, Orchestrates the entire process, setting material policies end using structured bills of material together with construction schedules to define or re-define priorities for Purchasing and Production. Production and Design use the material policies to develop standards, hull build strategies end the structured bills. Delivery of purchased materials and the kitting of components is carefully controlled to minimize inventory and storage facility investment. Product lead times are much reduced over traditional shipbuilding approaches due to clear priorities end the highly focussed task definitions inherent in the use of structured bills. In short, the shipbuilders studied by NSRP practice formal manufacturing.

MODEL ANALYSIS

MRP II

MRP II systems are often thought to work only in repetitive manufacturing environments. In fact, they can work for any manufacturer where Dependent Demand can be defined. This feature makes these systems particularly attractive to shipbuilders. The maintenabce of priority in Shipbuilding is difficult with any degree of accurasy using manual methods. There are just too many interim products to track. MRP II makes use of the strength of computers; manipulation of large amounts of data. Since the data is captured in one place any changes are immediately visible to all users. This information can then be made available to anyone who needs it.

There are problems in supplying MRP II to shipbuilding. A full discussion of these problems is beyond the scope of this paper. Instead, we will present a partial list to suggest areas for further study.

Nesting. A toaster manufacturer has to nest parts onto plates and shapes of raw material. That is he has to decide what combination of parts can be cut out of a particular plate or shape. Since thousands of identical parts will be made, this pattern or nest can be set once and re-used.

A shipbuilder has to perform the same task but for thousand. of unique items, requiring many unique nests. Tradionally this has been performed weeks or months in advance based on high level schedules or other groupings. In a formal system, the nest itself would have to be managed as an interim product limiting the flexibllity of the system.

Design end Construction Overlap, To reduce the total design end construction lead time, they are often run in parellel for the lead ship. This Can limit the amount of time available to prepare the BOM in advance of construction. It also prevents a total ship view of the detailed plan until sometime after construction has begun.

Construction and Activation Overlap To meet the schedules demanded by the customer, testing and activation of specific systems must begin before the ship is complete. As a result the definition of interim products becomes complicated when zone products must be integrated with system products that run through many zones.

Each of the problems described is solvable. Today major aerospace companies like Boeing and McDonnell Douglas are building products of equal complexity to warships using MRP II systems. We know of no technical reason why MRP II systems cannot be made to work in American shipbuilding.

JIT/KANBAN

The kanban system as stated previously works best in a repetitive manufacaturing environment. This makes it inappropriate for many shipbuilding manufacturing problems.

3 Note, this is not the traditional definition of expediting described earlier. These expeditors never disrupt internal schedules.

While Kanban itself is not generally applicable to shipbuilding its principles are. Reducing setup costs increases flexibility in responding to changing priorities. Increased flexibility makes it easier to build only what is needed when it is needed. Both of these principles are worthy goals for shipyards.

NSRP

The NSRP model has now been with us for 10 years. In that time, it has proven to be a useful framework for major gains in shipbuilding productivity. Yet many people are still struggling to understand how to apply the details on the shop floor. Among the difficulties often cited are: lack of top management commitment and understanding, organizational differences, and the complexity of naval versus commercial construction. We believe it is time to re-examine the NSRP model in the context of other manufacturing systems. This results in the following conclusions.

The NSRP model ia a form of formal manufacturing. It is, however, only a particular implementation optimized to support a specific business environment.

The NSRP model does not discuss the details of implementation on the shop floor. It presents a static picture of shop organisation and planning, materials and subcontracting policies. No guidance has been given on ways to adapt the *methods presented to a* different business sltuation.

The NSRP model has been difficult to implement on warships owing to the [illegible]

we believe that these are all issues of edication. By understendlng the fundamental concepts of Production and Inventory Management, common industry practices can be re-examined as to their impact on efficient manufaacturing. The NSRP model can be placed in context and analyzed for it." strengths and weaknesses as compared with other formal manufacturing models. Through broader education, it is possible to begin sorting out where business, organizational or procedural changes are required.

Educational opportunities are available from a broad spectrum of industries outside of shipbuilding. The Aerospace and Defense industries are an especially valuable resource. Through organizations like the American Production and Inventory Control Society, a vibrant discussion of manufacturing productivity issues is going on in our own backyards. It is time that shipbuilders joined the discussion.

CONCLUSIONS

Most discussions of shipbuilding productivity involve process improvement. Regardless of how efficient a particular process is though, it cannot contribute to the goal without having the right material at the right place at the right time. Nor does the efficiency of a process contribute to the goal if its output is wasted on the wrong product. These are issues not of process but of Production and Inventory Management. We have endeavored to show that shipbuilding, like any manufacturing business, must address these issues in order to be competitive.

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