VIRTUAL MANUFACTURING CONCEPT FOR SHIPBUILDING

Shipbuilding process is very convoluted process, which starts from initial feasibility, studiesrequirement analysis, then through the design and production stages, it ends in commissioning of the ship. Current shipbuilding system design methodologies produce multiple models of the eventual production system. These models reflect either the designer’s view of some subsystem, some level of abstraction, or some developmental stage in the design of the system. These models serve to break the complex system design into smaller, more manageable sized problems.

For a shipyard to be effective in terms of cost, time and quality, there is a need to integrate these models before the production goes to physical system. Lots of efforts have been taken in this regard. However, none of the current integration efforts support integration of manufacturing design methods and tools. Generally in these efforts only exchange of static (structural) information is taken into account, but the integration of dynamic (state) information among systems, is not addressed.

Co-ordinating and implementing the design efforts of the multi-disciplinary teams to production stage is a difficult task. Various disciplines utilise different methods and designers have their own tools for executing these methodologies. The challenge for shipbuilding is to utilise a continuum of information such that work can be accomplished more effectively, design and production methods more thoroughly optimised and time scale reduced significantly. Solving these problems requires a new technology that enables prototyping of complex multi-model manufacturing systems like a shipyard, what we call virtual manufacturing engineering. Virtual manufacturing engineering integrates independent domain specific design tools into an integrated system for the design of large, complex systems. Such a technology also enables the systematic integration of new design tools and is easily upgradeable to new design domains, methodologies, and technology.

The vision of Virtual Manufacturing is to provide a capability to Manufacture in the Computer see Figure 1. In essence, VM will ultimately provide a modelling and simulation environment so powerful that the fabrication/assembly of product, including the associated manufacturing processes, can be simulated in the computer. This powerful capability would take into account all of the variables in the production environment from shop floor processes to enterprise transactions. In other words, VM will accommodate the visualisation of interacting production processes, process planning, scheduling, assembly planning, logistics from the line to the enterprise, and related impacting processes such as accounting, purchasing and management.

The concept of virtual manufacturing comes through US defence ‘s combine efforts. The Virtual Manufacturing has been successfully used in different industries. Boeing used virtual manufacturing in the development and production of Boeing 777 airplane, the first airplane to be 100 percent digitally designed. Boeing was able to build plane without the benefit of drawings, mock-ups or development fixtures. Chrysler has designed and produced three vehicles using virtual manufacturing--Chrysler Concorde, the Dodge Intrepid,
and the Dodge Durango. "According to Chrysler, using its virtual manufacturing system, it was able to cut the development time of its new 1998 Concorde and Intrepid from 39 to 31 months.

The nature of production and manufacturing systems in Shipbuilding is little different from other manufacturing industry. But the advantage of VM can be employ in Shipbuilding for more effective and efficient production.

Virtual Manufacturing

In Lawrence Associates’ Virtual Manufacturing User Workshop report, Virtual Manufacturing (VM) is defined to be an integrated, synthetic manufacturing environment exercised to enhance all levels of decision and control.

**Synthetic:** a mixture of real and simulated objects, activities and processes  
**Environment:** supports the construction and use of distributed manufacturing simulations by synergistically providing a collection of analysis tools, simulation tools, implementation tools, control tools, models (product, process and resource), equipment, methodologies and organisational principles (culture)  
**Exercising:** constructing and executing specific manufacturing simulations using the environment  
**Enhance:** increase the value, accuracy, and validity  
**Levels:** from product concept to disposal, from the shop floor to the executive suite, from shipyard equipment to the enterprise and beyond, from material transformation to knowledge transformation.  
**Decision:** understand the impact of change (visualise, organise, and identify alternatives)  
**Control:** predictions effect actuality
Figure 1  Virtual Manufacturing
Three major paradigms have been proposed for VM:

- **Design-centered VM** provides an environment for designers to design products and to evaluate the manufacturability and affordability of products. The results of design-centered VM include the product model, cost estimate, and so forth. Design-Centered VM adds Manufacturing information to the IPPD process with the intent of allowing simulation of many Manufacturing alternatives and the creation of many "soft" prototypes by "Manufacturing in the Computer." The Design-Centered VM is the use of manufacturing-based simulations to optimise the design of product and processes for a specific manufacturing goal such as: design for assembly; quality; lean operations; and/or flexibility.

- **Production-Centered VM** provides an environment for generating process plans and production plans, for planning resource requirements (new equipment purchase, etc.), and for evaluating these plans. Production-centered VM adds simulation capability to manufacturing process models with the purpose of allowing inexpensive, fast evaluation of many processing alternatives. This can provide more accurate cost information and schedules for product delivery. An example would be evolutionary re-engineering/optimisation of a fabrication facility. Production-centered VM adds analytical production simulation to other integration and analysis technologies to allow high confidence validation of new processes and paradigms.

- **Control-centered VM** offers the environment for engineers to evaluate new or revised product designs with respect to shop floor related activities. Control-centered VM provides information for optimising manufacturing processes and improving manufacturing systems. Control-Centered VM is the addition of simulation to control models and actual processes, allowing for seamless simulation for optimisation during the actual production cycle.

In summary, Design-centered VM provides Manufacturing information to the designer during the design phase. Production-centered VM uses simulation during production planning to optimise lines/shop floors, including the evaluation of processing alternatives. Control-centered VM uses machine control models in simulations, the goal of which is process optimisation during actual production.

**Virtual Manufacturing System in Shipbuilding**

Shipbuilding consists of different activities/process including tendering, design, production, planning, material, finance etc. Virtual Manufacturing System (VMS) for a shipbuilding enterprise will look like figure 2, where VMS provides a common platform to all the activities in form of a **information product data model**. It provides an integrated synthetic manufacturing
environment exercised to enhance all levels of decision and control in different activities/processes of shipyard. This is an integrated computer-based model that represents the physical and logical scheme and the behaviour of real manufacturing systems. The main features of a VMS are

- VM focuses on improving manufacturing processes by the employment of a model-based approach, which leverages simulation capabilities.

- VM serve as a tool for implementation of IPPD practices with a special focus on cost estimation and control functions.

- The basic vision of VM is to "make it virtually" before we "make it for real". However, VM does not simulate all of the activities. For example, VM does not simulate the design process. It supports the design process. VM does not simulate reliability or quality engineering, but in many cases a VM simulation may need access to design, reliability, quality and other kinds of information.

- VM is model-based manufacturing, with tools that leverage those models. Primary among the techniques used is simulation, which can reduce some costs of manufacturing and allow exploration of many options in a mixed real/computed space.

- VM adds simulation to control processes to allow for expedited re-engineering/improvement of processes.

- VM is not a single solution, architecture or monolithic database approach. It is a collection of many smaller, incrementally implementable tools (which leverage modelling and simulation), together with some more overarching concepts.
Virtual Manufacturing System for Shipbuilding

The architecture of a Virtual Manufacturing System is shown in figure 3. It consists of a common database at bottom level, with manufacturing facilities on top of it and the product model at top. With regard to shipbuilding these terms can be defined as follows.

A Common Database

Virtual manufacturing requires a robust information infrastructure that comprises rich information models for products, processes and production systems. So for a fast access / retrieval and manipulation of information, VM requires a structured database back ending. Different database systems like Oracle, Sybase etc can be customised used for this purpose. The object-oriented database approach is best suited for this purpose since different information models will be comprised of different independent entities.

A Manufacturing Environment

A Manufacturing Environment represents the production systems ‘s static view. This will depict the system’s capabilities and performance. For a shipyard capabilities and performance is consist of the static facilities available at that instance. Like Crane handling capacity, cutting and welding equipment ‘s performance capabilities etc. A manufacturing environment is static in sense that it can not be changed without having any big infrastructural change. For simulations of a production process static factors plays an important role in determine the maximum efficiency. All production and process plan has to be developed keeping in mind the capability and performance of physical production system. This model is necessary in order
to assess the feasibility of manufacturing a certain product design in a certain production system. In addition, knowing the system’s capabilities and performance, it is possible to compare them with the production requirements of the design, and, thus, assess the manufacturability of the product design with respect to the production system.

A Manufacturing Resource Model

The Manufacturing resource model represents the system’s dynamical behaviour i.e. dynamic view. This model consists of all the variables, which are time dependent in that particular period of time. The inventories, material logistic are the examples of such variables. These variables should be kept in mind while simulating the process. A manufacturing resource model comprises of information related to all dynamic variables of given production system. This system view is necessary to predict production performance based on given demand characteristics and the System State. Performance attributes of interest include cycle time, inventory levels, and just in time (JIT) delivery.

A Virtual Prototype Model

Virtual reality is the interactive computer simulation from the user point of view. It requires immersion in the virtual environment, real time simulation and realistic visualisation of the scene, and a non-command, intuitive user interface. VR is backbone of any system using Virtual Manufacturing. The effectiveness of simulation and modelling is enhanced by use of Virtual environment.

From last few years cost/performance ratio of VR has decreased. The new generation of VR software products is appearing, making a more efficient use of the hardware resources, and with a better integration with existing CAD/CAM/CAE application encouraged more extensive use of VR in design and production.

The extensive, integrated tools of virtual reality (VR) in industry can change design, manufacturing, and assembly radically. VR has certain advantages over traditionally CAD systems available in shipyards.

The next important part of VMS is virtual prototype, this is important for visualisation point of view, it gives a feel of being in real system. A VP is defined as a computer-based simulation of systems and subsystems with a degree of functional realism comparable to a physical prototype. These are used for test and evaluation of specific characteristics of a candidate design.

The idea behind Virtual Prototyping is simple, the design of prototypes in a virtual environment (computer) to save production costs and reduce design time. VP is a top-down. In order for a VP to operate as a true substitute for a physical prototype it must meet certain demands. It must permit all members of the development team to simulate the performance and effectiveness of product and process designs, at a level of fidelity comparable to that, which would be achieved in physical prototyping.

In order to achieves this level of interaction between design team members a collaborative working environment must be established, preferably one, which integrates already existing CAD systems. The underlying product
model of the VP environment is STEP (Standard for the Exchange and the Representation of Product Model Data) - based and uses an object-oriented data management approach. This allows concurrent prototype alteration and manipulation within the team, and with the development of high-speed parallel processing systems, promises real time applications.

Some of the real time applications necessary to achieve a true VP include driver-in-the-loop simulations, dynamic performance simulation, dynamic stress and life predictions, and design sensitivity analysis.

The Product Model

The concept of product model for a ship is not new. A product model is at the top of the VMS. Since large, complex product engineering artefacts, of which the ship is an example, are generally associated with the generation and management of vast quantity of complex, interrelated product data. These data are concerned with all aspects of the product, including its geometry, topology, functionality, the associated production process, production planning and control, materials, quality control and so on. Product models provide the facility to organise these data efficiently.

Technology Needs for Implementing VM

Following are technology issue, which affect the implementation of Virtual manufacturing.

- Visualisation and simulation technologies, including more affordable hardware.

- In addition to M&S requirements, considerable work is needed in database/knowledge base technology, shifting the "intelligence" from the application to the data itself.

- Development of a formal, structured methodology for design abstraction. The purpose of this methodology would be to enable designers and engineers to discuss, manipulate and represent design concepts in a way that is computer-interpretable. So, that various software tools could be built that "understand" what kinds of information are relevant in a given design problem or context and deliver that information to a designer or engineer in a timely manner and in the most useful form.

- Development of Models and Simulations. Issues include determining what to model (or establishing an approach for doing so), and determining the degree of abstraction and level of depth required. The abstraction and depth issues are related to the design phase (e.g. concept vs. detailed) and the design goal (e.g. the degree to which a design must be manufactureable vs. the degree to which the manufacturing process must be developed to accommodate the design). The flexibility and maintenance of models and simulations is also an issue, as is integration
of a simulation with data from all relevant cross-functional areas (e.g. reliability, quality), and business areas (e.g. vendors, sub-contractors).

- Human interface technology is needed for complex systems. Sophisticated computer-aided Design (CAD) software today, while improving, still requires a significant learning curve and generally presents to the user a very complex interface.

- Multi-level distributed security. Information security.

- Advances in Object oriented dynamic event-based modeling are needed.

- 3-D surface-based modeling.

- Common kernels for model component exchange. For design-centered VM, this would probably be a 3-D solids-based, possibly feature-based model; for production-centered VM, this would probably be event-based, possibly network-based.

- A general capability to integrate dynamic, distributed, collaborative models.

**VMS & Data Model**

A VMS rely on modelling and simulation. It emphasis on to develop models for the representation of product information, including product configuration and product shape (geometry and topology and form features).

Manufacturing process models typically relate critical process parameters to those attributes of the product that are significant to the product's function. Process models assume many forms including physical or mathematical models derived from first principles, statistical models derived experimentally, computer process simulations, and simple tables and/or rules found in handbooks. However, there has been little work to use more sophisticated process models in an integrated fashion with product design. An example of such work is the integration of a process planning system with a mathematical model that predicts the weld quality in fabrication shop.

Production system models comprise the third important component of the information infrastructure for virtual manufacturing. Let there is a rolled plate, which has to be used in some forward part of a ship. Now the product model will be comprises of all the information of the interim product like material, geometry, gaussian curvature etc.. A process model will comprise of the information for moulding the rolled plate from a straight plate, the typical information for a CNC will be comprised of the pressure applied for achieving that degree of curvature etc. .The Production process model will contain the information about the availability of CNC at given time (static view), equipment’s scheduling for a particular day for given set of job (dynamic view).
Virtual Manufacturing in Ship Production System

Virtual manufacturing applications require a robust information infrastructure. Based on this infrastructure, decision support systems may be developed to predict or simulate key manufacturing activities in the computer. Following are a few areas in ship production system where VM can have major contribution in current state of art.

Validation and Evaluation of Process Plans

VM may validate the process plan in the computer, thus eliminating the need for costly prototypes. Having a valid process plan, VM may estimate the manufacturing times and costs accurately. Beyond plan verification, virtual machining may be used to estimate accurately the merit of a process plan, and, based on this evaluation, determine appropriate process conditions to improve (and even optimise) the plan.

Process Design

Process models that describe the process physics are critical for the construction of dependable virtual processes. A process model helps in assessing the feasibility of producing a design with a certain set of manufacturing processes and evaluating the ease of manufacture with these processes. A process model developed by capturing the physical models of various processes (i.e. analytical, statistical and simulation-based models) and to provide unified interaction mechanisms with the virtual manufacturing environment. With Process model, it is possible to construct virtual process and use them to:

- Determine the feasibility of a process and a given process plan to yield the desired product characteristics
- Evaluate process performance with respect to processing time, cost and quality of the manufactured product
- Support process design, i.e. the tuning of critical process parameters to optimise process performance.

Optimisation of Production Plan and Schedule

Discrete event simulation has traditionally been considered a powerful tool for production applications. In operations management, simulation may support production planning and scheduling, especially when combined with powerful optimisation tools. For example, simulation combined with perturbation analysis may be used to determine optimal threshold values for the Work in Process at bottleneck workstation. As another example, simulation may be combined with simulated annealing or genetic algorithms to optimise the schedule of bottleneck workstations.

In product/process design simulation may play a significant role in integrating product design and process planning with production planning and scheduling. Given a design and a process plan (or a set of alternative
plans), various production scenarios may be simulated to determine the impact of the new product on the operations of the shop. By doing so, the designer will be able to determine early in the design stage the effect of certain design decisions in production planning and scheduling. Furthermore, the process planner will be able to determine alternative plans that are appropriate for certain states of the shop. It should be emphasised, however, that product design and process planning are time-independent (static) activities, while production planning and scheduling is dynamic activities.

**Implementation of Virtual Manufacturing**

Virtual manufacturing concepts can be implemented in following breadth of area.

- The details of product design are presently captured as part of the current information system in a fairly systematic way, manufacturing process details often are not. Since VMS uses the expert systems to capture the knowledge of subject matter. The knowledge-based system is used for decision support. So the information accumulation of product as well as of corresponding processes over the time will serve as guidance for future. Using expert systems in conjunction with VM would be a significant improvement by providing process capability and cost information to guide the product design process.

- Capital investment decision must be more accurate in shipbuilding for a shipyard to be competitive in global market. Manufacturing models and simulations will and are having some influence on capital decisions currently, but this use is isolated. VM should be widely used in capital investment decisions since it should allow more credible comparisons of investment alternatives and should also provide history on the performance of past investments, which is frequently hard to obtain in the current environment.

- Since major work involved in Ship production is assembly of different parts, installation of machinery, piping etc. All these required active involvement of supplier in manufacturing process. The use of VM will have a significant impact on supplier management. Easy access to better quality and more detailed information on costs, capacity, process capability and lead-times will lead to more profitable make/buy decision. Major subcontractors will have early involvement in product design and planning through the Virtual manufacturing ‘s enterprise approach.

- VMS enhance the effectiveness of systems integration in the design process, and as a result, minimise interference between subsystems, and reduce the dependence on hard mock-ups. Major improvements to the transition from design to production are envisioned because of much stronger and more effective influence of process capacity and manufacturing cost information on the product designer as well as the ability to do many more design iterations prior to committing to physical manufacturing. One spin-off result should be in providing materials that
come out of VM and the design process to be used in training the manufacturing workforce the computer based models and simulations could be readily adapted to work instructions or training materials.

- The move toward VM will necessitate finer-grained, more accurate cost information than can typically be provided by current cost accounting systems (and VM cannot succeed without this kind of information). This will, in turn, accelerate the current trend toward activity-based accounting systems and other accounting system changes that allow detailed and accurate product costing. A Product-oriented design and construction (PODAC) cost module has been suggested to develop a product-based production driven cost estimating tool that will be used by shipbuilders to assess the cost of innovated and advanced technologies proposed for naval application. Incorporating this approach in VMS will provide a more accurate cost information.

- With the tools like Modelling and Simulation (M&S), VM can have a major influence on management identification of risks and the merits of alternative courses of action at all levels of management.

- VM will enhance the credibility of responses to "what-if" queries significantly at all levels of the organisation to be based on accurate and credible information.

- VM will potentially accelerate the current trend toward weaker functional distinctions within different offices in shipyard by promoting the widespread sharing of information and enhancing close inter-functional working relationships.

- Significant improvements to work instructions will be seen through the ready availability of graphics. Much better tooling will be available on the shop floor with features that make it easier for the worker to succeed via access to better instructions and illustrations to promote error-free tool use. This will also make it easier to accommodate the envisioned drop in the average skill and education level of shop-floor workers. The proofing of designs and manufacturing processes in the computer prior to commitment to hardware should sharply reduce the problems on the shop floor.

**Benefits from VM**

Virtual Manufacturing is one of the key technologies, which allows us to go beyond the assumptions driving the historic acquisition strategies.

- VM can support the generation of more reliable estimates of production costs and schedule because the models are based on actual processes, not just parametric.

- Modelling and simulation (M&S) can significantly improve production flexibility, hence, reducing the "fixed costs".
Reliable predictions of costs, risk and schedule can substantially improve the decision making process of acquisition managers.

More producible designs moving to the shop floor and higher quality work instructions to support production ensure best quality. Thus Total Quality Management (TQM) can be achieved.

Discussion and Critical Assessment

Key aspects and challenges for uses of Virtual Manufacturing in Shipbuilding are:

- The design and manufacturing practices in a shipyard are mainly focused for immediate goals like initial design technology is mainly focused on supporting detailed design activity. CAD software systems, while providing increasingly sophisticated means of manipulating shape and form represented in the computer, are poor at representing the information critical at conceptual design. For VM to have an impact on this critical phase of design, it will be crucial in next-generation systems to seamlessly integrate different stages in design and production of a ship.

- In any design technique, there is a trade-off between computational requirements and accuracy. Some approaches examine the design directly: these are less computationally intensive, but in some domains it is difficult for them to give good results. Other approaches generate and evaluate results and plans. These can produce accurate results in cases where direct approaches have problems, but can require large amounts of computing time. As the cost of computing power continues to decrease, we anticipate that the computational requirements will become less of a limitation, and thus plan-based approaches will become increasingly attractive. Examples are FEM and CFD analysis, which can be extremely helpful in design stage of ship.

- Existing production practices deal largely with individual manufacturing processes. So VM must be able to address multiple processes and their trade-offs. Furthermore, since problems discovered by design-for-assembly (DFA) analysis are closely related to manufacturability analysis, better communication is needed between DFA evaluations and manufacturability evaluations.

- Virtual manufacturing, gives opportunity for assessment of a candidate design and to provide accurate estimates for processing times, cycle times and costs (including inventory), as well as product quality. This is because VM will be able to model both the processes employed for the product's manufacture and the production process.

- Virtual Manufacturing gives a tool that can intelligently assess the trade-offs between conflicting design requirements and manufacturing constraints.
Process planning is a very complex task which requires considerable experiential knowledge---and thus for the foreseeable future, most computer aided process planning systems will require a significant amount of supervision by an experienced human user. Since variant process planning in the traditional sense is basically a scheme for retrieving existing process plans from a database, the role of VM in supporting traditional approaches to variant process planning appears to be rather limited---but in the case of generative and hybrid variant/generative approaches. VM will have a clear and critical role in producing more realistic plans and evaluations.

Virtual manufacturing (VM) plays a significant role in distributed manufacturing, since it may improve design critiquing and process planning. These improvements will result in better designs and more informed partner selection. Furthermore, VM is expected to support distributed design if it provides protocols and computer aids for negotiation.

Virtual environments may provide visualisation technology for VM and the Virtual Prototyping may provide technology for making virtual prototypes, which is an essential component in the virtual product life cycle, for VM. The technologies from virtual enterprise, such as information exchange protocols and standards, can benefit VM.

VM may provide information about the product, process, production, and shop floor control to be shared over networks.

Object Oriented technology may provide a powerful representation and classification tools for virtual manufacturing. Object Oriented technology may also provide a common platform for the information sharing between VM centres. Furthermore, Object Oriented technology may provide a richer way to store/retrieve/modify information, knowledge and models and reuse them.

**Conclusion**

The introduction of the virtual manufacturing enables a complete electronic environment in shipyard, which will have the following specific business benefits:
- Reduction of the cost in design, construction and repair of ships.
- Reduction in time from design to production.
- The improvement of the quality of both the processes and products throughout the complete life cycle.
- The creation of interoperable environment essential to computer, supported co-operative working, concurrent engineering, work flow management, operational decision support and emergency response.
- Improved management of safety by both the industry and the regulator.
So in conclusion we can say Virtual Manufacturing provides and support an environment, which helps in materialising the ultimate goal of any shipbuilder of cost and time effectiveness.