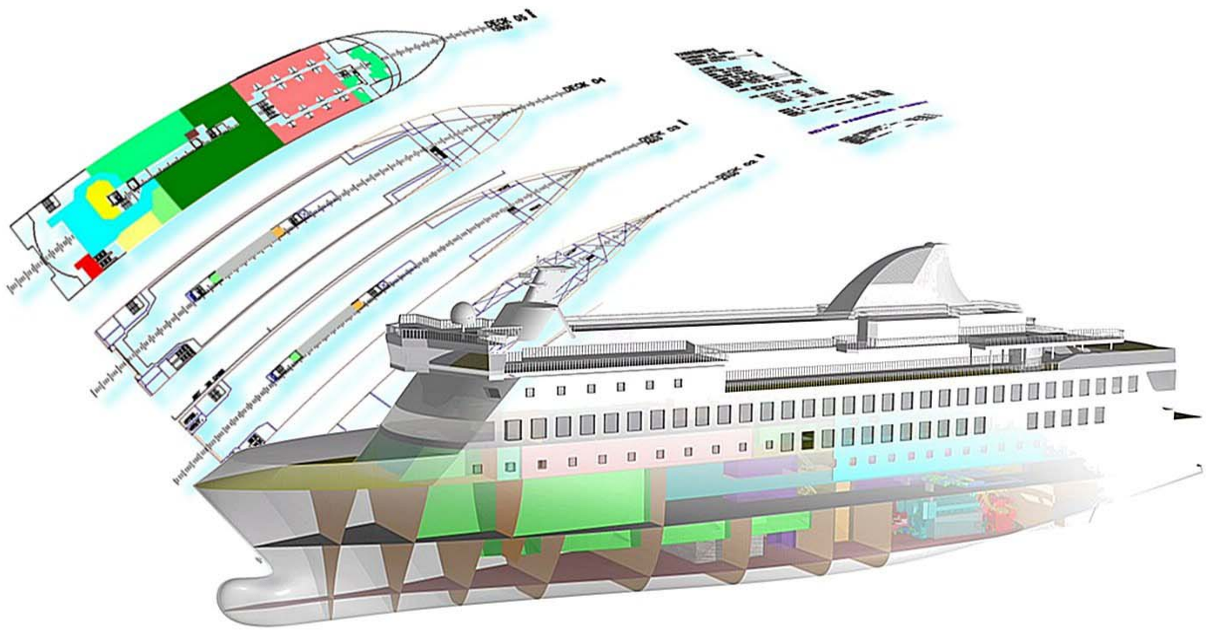
IBM PLM Version 5 Solutions for Shipbuilding

Setting the course and strategy for digital shipbuilding

Digital Manufacturing: The Virtual Shipyard



An IBM / Dassault Systèmes Thought Leadership Paper

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Preface

As the leading providers of information technology solutions for the global shipbuilding industry, IBM and Dassault Systèmes have worked with many major yards, design companies and consultants, to understanding the shipbuilding process from concept to float-out and to identifying common challenges and devising innovative, end-to-end solutions.

Highlights of that effort are offered in a new Thought Leadership Series of papers called *Setting the Course and Strategy for Digital Shipbuilding*. These papers are jointly authored by IBM and Dassault Systèmes. Each paper examines a different aspect of the challenges currently facing shipyards and the ways in which Product Lifecycle Management from IBM (PLM) has been designed to resolve them.

This paper, "Digital Manufacturing: The Virtual Shipyard," is one in the series. It focuses on new technologies for production planning, including process simulation, facility design and layout, and digital manufacturing. Other topics in the series will include overviews of shipbuilding economics; IBM PLM Shipbuilding vision; solutions and offerings; best practices; and PDM, digital mockup and collaboration. Some papers in the series will be confidential and subject to non-disclosure agreements with customers. This paper is not confidential.

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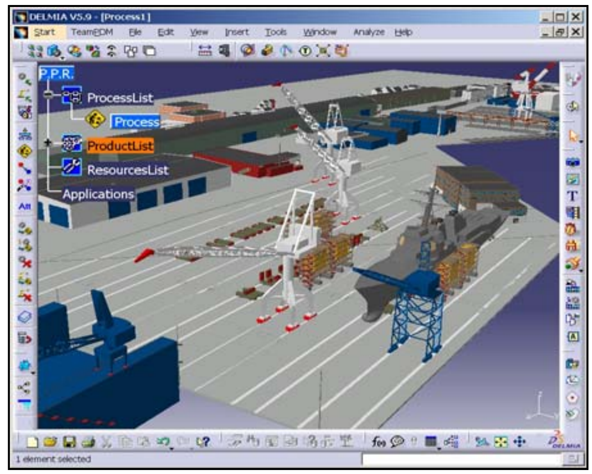
Introduction

Advanced production planners face new challenges in building today's ships. Not only are onboard systems far more complex and interdependent than before, but economics dictates that many will be built by suppliers at off-yard sites. The risk of miscommunication of requirements or design changes is high. With corporate consolidations, portions of a ship may be fabricated in multiple locations and then brought together to be integrated.

This "build anywhere" philosophy introduces challenges to taking advantage of the capabilities of each yard and defining the optimal state of the section to be delivered by each supplier. Many of the ship's systems must be installed so that they can be easily swapped out at some future date for updated technology. Coordinating suppliers with internal production requires far greater precision than ever before. When several ships are being built at the same time, there is competition for key equipment and yard area as well.



This paper examines the digital manufacturing solutions in IBM PLM, based on the Manufacturing Hub and the tie-in between digital design, engineering and manufacturing. Digital Manufacturing deals with both Design-for-Manufacturing and Design-for-Assembly. It is used to determine the optimal production plan, taking into consideration real-world constraints.

The philosophy and use of the Manufacturing Hub is described in detail later in this paper. It serves as a common database offering widespread integration benefits between design, engineering and manufacturing applications. The Digital Manufacturing environment enables the manufacturing team to influence the design to reduce the cost of manufacturing and eliminate engineering change orders caused by previously undetected problems with manufacturability. Data in the manufacturing hub also provides a rich resource for Maintenance Planning and the creation of 3D Maintenance and Repair Instructions. High-level Process Planning by the Advance Planners during the conceptual design phase ensures that the units of construction can be efficiently manufactured in yards and in supplier facilities. Because a Digital Manufacturing environment allows the discovery of producability problems early in the design cycle, the cost of change is minimal.

During the detail design phase, detailed planning and process design is finalized and verified in a 3D environment. These producability studies can be used to create 3D work instructions for the shop, unifying the spectrum from concept design through production execution. Digital manufacturing includes the creation of the production system, the planning of the production process and verification of the sequence of operations using simulation to support design for manufacturing. The functions supported include process planning, process verification, time measurement, layout planning, ergonomics, robotics, NC simulation, yard material flow simulation, production management and 3D Electronic Work Instructions.

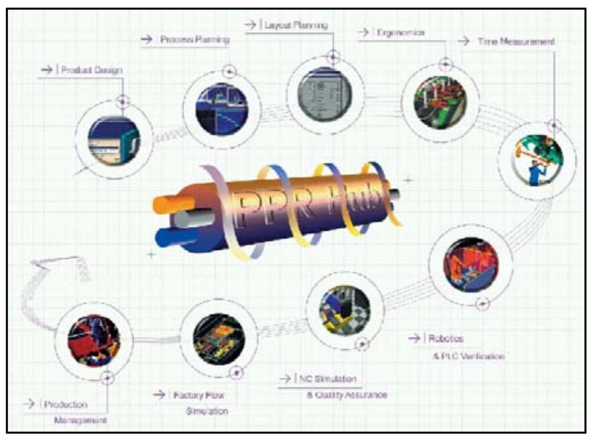
The Manufacturing Hub architecture provides a common, shared manufacturing database that starts at the conceptual level before CAD is available and serves as the repository for detailed process plans and manufacturing bills of material that support production. It becomes the “authority” for the “as planned” data for each hull number. It also defines the deliverables from suppliers, providing an in-process status of the ship sections yet to be integrated but not represented in the “as-designed” models.

References to product data in the Engineering Hub are updated as the product design evolves. The ability to maintain change control and configuration management of the product data in the Engineering Hub – along with the references to this product data in the Manufacturing Hub -- is critical. Applications in shipbuilding like panel welding, machinery installation, block assembly, outfitting and painting are described below.

Engineering and production managers will quickly see the benefits of having seamless integration between digital design and digital manufacturing using an integrated, authoritative build-to, buy-to and support-to database. This common, shared database ensures that all participants work with then-current data for design and manufacturing.

Product Process Resource Hub

The Product- Process- Resource or PPR Hub, contains both the Engineering and Manufacturing Hub mentioned above. It is a unique data strategy for digital manufacturing that provides storage and management of all product, process, and resource information required for production system design - from early ship design concepts through production.



The PPR model is at the heart of IBM Product Lifecycle Management (PLM) solutions, ensuring the integration between CATIA, ENOVIA and DELMIA. CATIA provides the product solution; DELMIA provides the process and resource solution; and ENOVIA provides the data and workflow management capability within the 3D IBM PLM offering.

The PPR Hub is an application- oriented database solution based on worldwide data standards that:

- Integrates solutions with historical data, making it available for company- wide use.
- Retains data in logically- linked relationships so that data must only be physically stored once.
- Provides the ability to generate status reports during every planning phase.
- Increases planning accuracy by promoting the transparency and consistency of data.
- Provides all users the same up- to- date data.
- Reflects any data change immediately for all users.

This paper focuses mainly on the Manufacturing Hub part of PPR Hub.

Driving Production

Yards worldwide are undertaking significant facility upgrades with one objective in mind – to streamline production. Waterfront expansion, larger high-bay assembly buildings, larger crane lifting capacity, improved materials handling, assembly lane modernization, robotic welding panel lines and integrated pipe bending are just a few of the upgrades being made. Why are yards making these changes? One answer is that the economics of shipbuilding are rapidly changing and only those with adaptable and lean manufacturing practices will be able to bid on new ships and grow profit margins.

Without a doubt, the designs of most ships are more complex and more integrated than ever before. Yards have become increasingly dependent on outsourcing, both to other yards within the same corporation and to consortium partners. In a sense, yards are engaged in distributed manufacturing. The emphasis is on CAIV (Cost As an Independent Variable) and affordability, where pre-assembly, pre-outfitting and Just-In-Time (JIT) are now given conditions.

But outsourcing increases the size of delivered systems and puts a premium on ensuring the relevant system interfaces, structures, etc. are ready to receive. Many times the system being received is in an “in-process” state. Some of the parts may be in an installation kit, which is not represented in any design drawings or models. The high costs of rework and physical prototypes, combined with competition for equipment, assembly space and materials handling when multiple ships are being built simultaneously, make process planning and digital manufacturing attractive technologies.

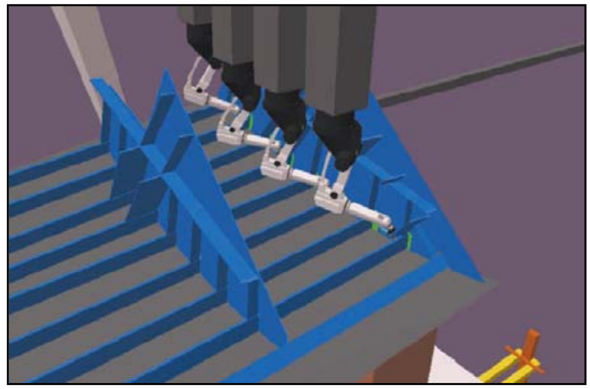
Outside the yards, owner/operators are demanding smarter and more cost-efficient ways of manufacturing. Prior to IBM PLM, concurrent product and process design was impossible and production system development was a sequential process. Today, with IBM PLM Solutions to maintain the relationships between the Product, Process and Resource data models, both design and production can be integrated, optimized and brought, quite literally, to the waterfront and to each yard worker.

Given the new economics of shipbuilding, the ideal Digital Manufacturing solution is one that provides a bridge between design and manufacturing execution and enables simulation-based design where no physical prototypes are required. Digital Manufacturing takes place in a virtual, collaborative environment. The Vision for the process is one that:

- Promotes design standardization;
- Derives detail from functional requirements;
- Derives production data from planning;
- Validates the plan as buildable and efficient;
- Supports Just-in-Time deliverable extraction; and
- Delivers applications that use a common, shared Product, Process and Resource data repository.

Digital Manufacturing

What is digital manufacturing? Essentially it is a computer technique for defining all the steps necessary to build a product (structural assembly, install an engine, join blocks together, bend pipe, etc.), test them for completeness, and generate machine and work instructions to manufacture them. The overall phases are: Process Planning; Process Detailing and Validation; Resource Modeling and Simulation; and the extraction of Manufacturing Data and Work Instructions.



What are the goals of Digital Manufacturing and what is it trying to accomplish? While there are many objectives, the three most critical are to shorten time-to-production; dramatically reduce rework; and improve craft labor utilization and efficiencies.

Digital techniques focus on reducing production schedule variances, avoiding unbuildable or ergonomically unsafe conditions, minimizing change orders after design freeze, and shortening response time to changes and unplanned conditions in the yard. Since shipbuilding has become such a collaborative effort between suppliers and often is done in collaboration with other yards, other goals include maximizing pre-outfitting during hull section assembly, early assessment of design for production, increased return on production assets, and minimal work in process.

Benefits of the Manufacturing Hub Approach

Shipyards are realizing clear benefits by taking the Manufacturing Hub approach. Unlike the legacy systems in many yards today, the PPR Hub provides an integrated digital bridge between the Product data in the Engineering Hub and the Process and Resource data in the Manufacturing Hub. This provides a common, shared database for Product, Process and Resource data and the inter-relationships involved in manufacturing, maintenance and repair. This provides support for process verification simulations and discrete event material flow simulations that can be launched using the data in the Manufacturing Hub. It is the logical and data communications interface to the ERP/MES systems that support production.

Manufacturing today is a multi-user and multi-site activity. The PPR offers access to data in a collaborative environment and provides security and controlled access to authorized users. Because data views can be customized to particular user needs, the Hub offers additional benefits by managing configuration, effectivity, revision control and change management of the processes and resources.

As mentioned before, the PPR Hub is the logical integration point with the PDM system for product configuration and management. It also is the point for creating process and resource libraries to facilitate reuse of best practices and for storing existing shop layouts and equipment specifications.

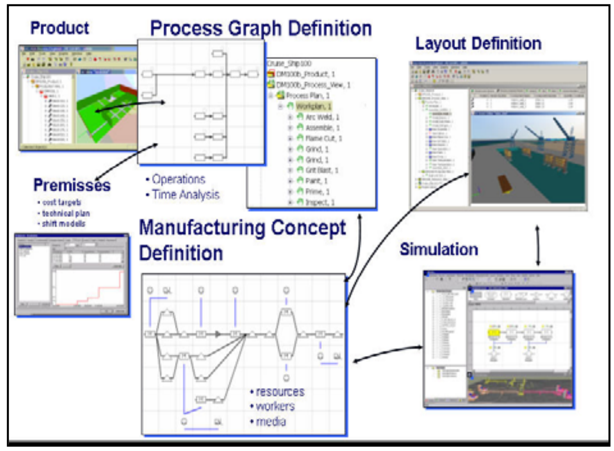
Perhaps the greatest benefit in the PPR Hub approach is the ability it offers for teams to work together. The PPR Hub facilitates managing large and complex process plans, while simultaneously retaining detailed production planning information for use on the next ship, even a year later. Most production planners realize that they “reinvent the wheel” many times because there has been no way to capture best practices and carry them over from one project to another. Digital manufacturing now offers a solution.

IBM PLM Digital Manufacturing is delivered in a series of steps that begin when DMU product models, produced in CATIA, and the product structure, produced in ENOVIA, are released for manufacturing. At this point they become linked to the MBOM in the Manufacturing Hub, where Process Planning, Detailing and Validation, Resource Modeling and Simulation take place. The end result is Manufacturing Data for machines and Work Instructions for personnel.

Process Planning

A brief overview

The first step in Digital Manufacturing is Process Planning. Product models designed and detailed in earlier steps by naval architects and systems engineering are passed on to production planners for manufacturing. Designs for large structural steel block assemblies, for example, must be "de-constructed" or broken down into the build units and the steps needed to build them. Process Graphs capture the sequence. IBM PLM workbenches accomplish this entirely in a 3D digital environment – no physical mockups or prototypes are involved. Constraints or Premises are added to the various tasks in the Process Graph. They might be critical due dates, cost or labor limits or the availability of key machinery.



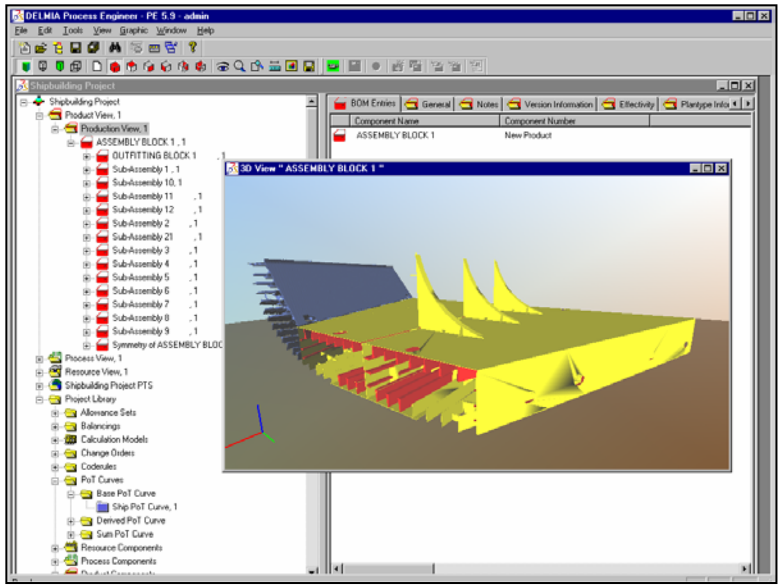
For example, within the steel structural block assembly, a particular sub-assembly of steel plates must be completed by a particular date. The date might indicate the availability of a particular welding robot. Once the Process Graph is completed, an initial manufacturing assessment is performed. Simple diagrammatic equipment layouts and shop-floor areas are assumed, but initial assessments can be made and bottlenecks identified. Detailed Layout Definitions of the yard's floor plans and actual equipment arrangements are then developed.

At a later stage, process engineers will enhance the original product models (structural block assembly, in this example) and add manufacturing features like cutouts, bevels, etc. as required by the various pieces of equipment to be used and the sequence of assembly.

Process Planning is an iterative process. The end result is a highly refined and optimized Manufacturing Concept Definition where bottlenecks have been removed, redundant process steps eliminated and equipment and shop-floor areas used to optimum levels.

The 3D digital process described here completely replaces traditional manufacturing processes, which relied on physical models and prototype designs. It captures and re-uses best practices and enforces constraints, such as the lifting capacity of cranes in a specific area. The net result to the shipyard is significant time and cost reductions with increased quality.

Process Engineering



In Digital Manufacturing, process engineers electronically collaborate with the ship's design teams. Using Process Engineer solutions, design assemblies ready for construction are extracted from the Engineering and Manufacturing Hubs.

A structural steel block, previously designed in a CATIA application workbench, is imported into Process Engineer. The initial work focuses on design intent – how the assembly is to function. ENOVIA ensures that all relevant supporting documents and product models are linked and available on demand.

Large assemblies are broken down into groupings of minor parts. In effect, the virtual assembly is "deconstructed" or taken apart. The intent is to create a build strategy based on a hierarchy of parts and sequences – which parts are needed first to build the next layer.

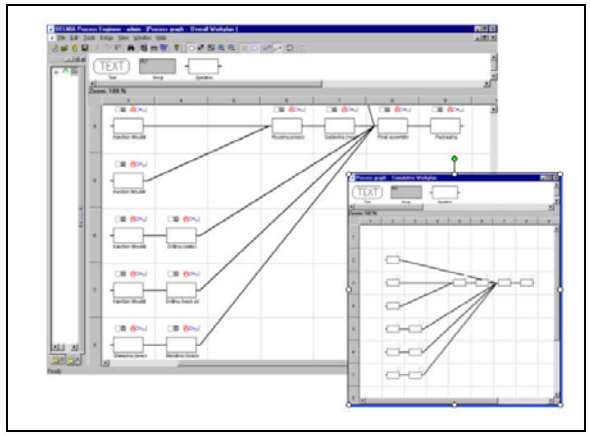
Since block production is one of the most common and resource-consuming activities in a shipyard, we will develop one to illustrate the process and the benefits of digital manufacturing. Using this example, production teams access a previously designed block and create a high-level process diagram or graph showing the general steps needed to build it.

At this time, the focus is on sequencing the steps and identifying which elements are interim products along the way. Little attention is given to how the product will be made, only what is to be made and in what order – parts and sequences.

Build strategies result in hierarchies that may differ from the product structure created in the design phase. There the focus was on part definition, standardization, design rules and meeting customer requirements. Differences between the two hierarchies are acceptable and the Engineering and Manufacturing Hubs maintain links that allow both views to coexist without duplicating data and while maintaining data synchronization. During Process Engineering, no additional parts or features for manufacturing are added.

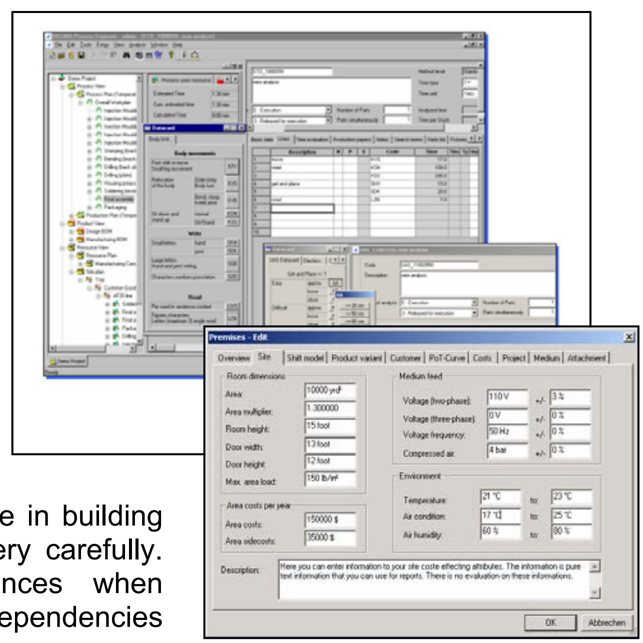
Process Graphs

Process Graphs serve as a convenient way to visualize complex build sequences. They resemble product structure hierarchies but, instead of mapping how product and part geometries relate, they define the order and relationship of parts in finished assemblies. The graph is a course model of future manufacturing, but not yet refined with considerations for actual equipment needed or the facilities of the yard. The Process Graphs show parts and tasks with hierarchy or combined in groups, thus supporting top-down planning. The next step is to refine the graph by imposing Manufacturing Constraints.



Manufacturing Constraints

Ship production is almost always constrained by cost, production rates, planning targets, schedules, production site space and the availability of machines for welding, painting, lifting or sandblasting. To reflect these realities, DELMIA Process Engineer provides a special workbench to define “Premises.” The goal is to simulate the reality of production as closely as possible. “Premises” are data values that generally impose a limit of some sort or establish a target such as resource utilization. They play a role later when scheduling or simulations are performed. Constraints include available shop-floor area, maximum costs, work shift labor rates, milestone dates, etc. Premise data are maintained in the Manufacturing Hub. To estimate the flow time for a Manufacturing Concept, time estimates must be established for each task.

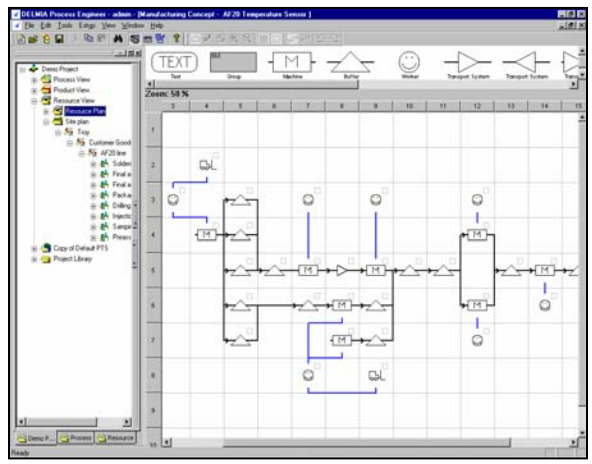


Time Analysis

Time is arguably the most precious resource in building ships. Most yards audit their work flows very carefully. These databases are invaluable references when estimating new projects and identifying dependencies such as craft labor.

Earlier steps in process planning have defined the assembly breakdown, graphed the sequence of tasks and imposed constraints (premises). Using internationally recognized time standards like MTM, or custom time standards for a specific yard, the Time Measurement workbench defines time as a resource for work processes and task completion. Reports for estimated times and process times, using a variety of methods, are possible. It is here that the operations and sequences defined in the process graph combine with individual time assessments to create a realistic picture of how long it will take to make the product and the duration of each sub-task. Typical time elements may be man-hours, man-days, yard operations calendars, machine turn-around cycles, etc. Once time has been defined and linked to the process graph, a general Manufacturing Concept is prepared.

Manufacturing Concept

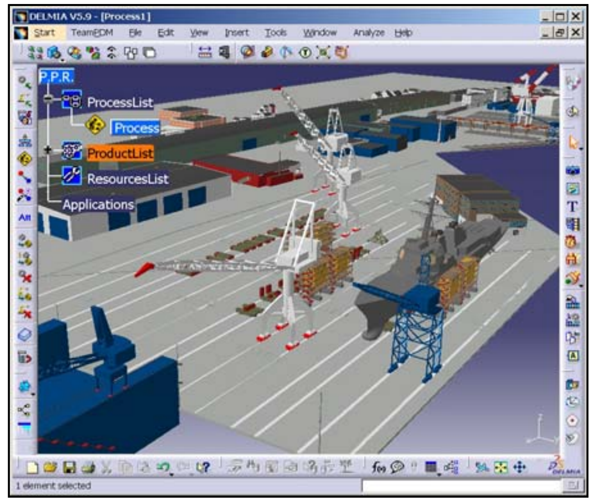


The Process Graph is re-used as a backbone to create the next step in the planning process: the Manufacturing Concept. The objective of the Manufacturing Concept is to allocate manufacturing resources to create a graphical overview of the manufacturing system that includes product, process and resources.

The Manufacturing Concept is a schematic layout that results from mapping the resources to the process activities. It includes activities that do not add value, such as move or inspection activities – the total of all processes and resources required for production. In addition to machines and workplaces, tools, transport equipment, buffer and test positions can be described in detail. The links between the objects are inherited from the process graph and new links can be added. The Manufacturing Concept also includes human resource planning. Product, process and resource have been brought together into one logical sequence of timed events where material flow, cost calculations and facility utilization are brought together. This Manufacturing Concept is the central definition upon which all subsequent layout definition and simulation is based. Typically, multiple manufacturing concepts are created to evaluate manufacturing alternatives.

Layout Definition

The Manufacturing Concept produces a schematic layout – a logical block diagram of the steps necessary to manufacture the product. But yards are constrained by practical considerations such as available floor area, actual equipment locations (robots, welders, flame cutters, pipe benders, sand blasting and painting, etc.) and transport systems including cranes and lifts. The Layout Planning workbench is used to convert block diagrams into 3D layouts that reflect these actual yard resources.

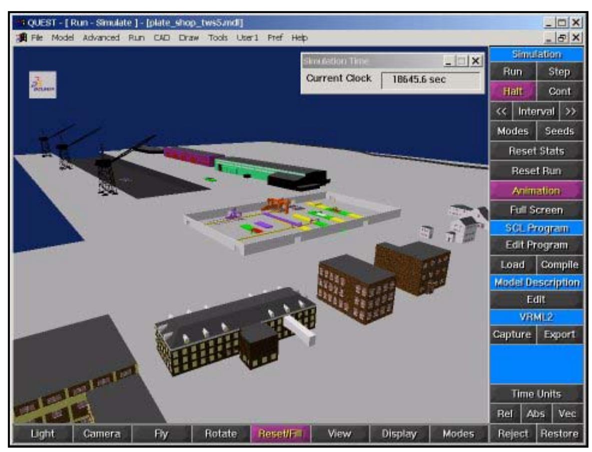


The Layout Planning workbench revises the Layout Definition by adding floor plans, equipment footprints and material lay-down areas. Bills of Resources, 2D and 3D workplace views, drawings and facility layouts are the result. Such outputs are critical in communicating the impact of manufacturing alternatives on the facilities and in assessing the ROI for renovating facilities or purchasing new capital equipment.

The Layout Planning workbench provides libraries of manufacturing equipment and supports “virtual equipment” definitions for “what if?” scenarios. Layout Planning has enriched the Manufacturing Concept to the point of creating a complete, digital definition of product, process and resource. Manufacturing analysis and simulation can be performed; it is here that digital manufacturing provides the highest payoffs by improving the project time line and controlling costs.

Discrete Event Simulation

A major benefit of the virtual manufacturing environment is the ability to analyze production scenarios and the payoffs from changing facility layout, resource allocation, scheduling, or of integrating product teams. Prior to this technology, most yards have only achieved optimal results in small and localized production processes. The ***QUEST™*** workbench supports discrete event simulation and is a combined analysis and visualization workbench providing stochastic analysis of the combined probabilities of all events in the process flow.

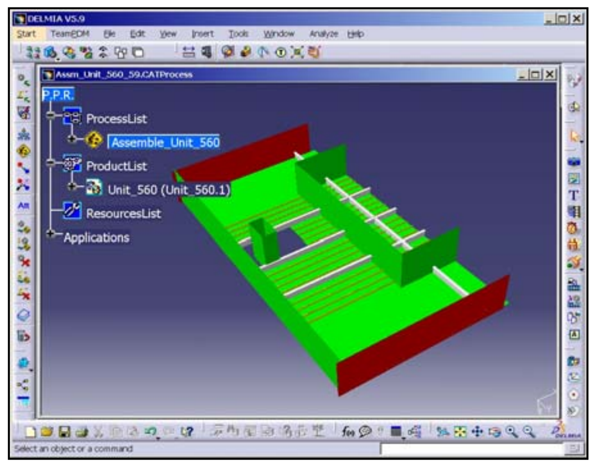


This provides a realistic prediction of the shop-floor throughput identifies bottlenecks and reports on asset utilization. Through a high-level simulation language, users define custom behaviors of process machines as well as human and materials movement. Sequences of manufacturing steps can be linked together to validate that they work and to visualize the consequences at startup or shutdown.

QUEST can accept 2D facility descriptions and develop more realistic 3D descriptions. In this way, the model can start off at a simple conceptual level of detail and then evolve as the design process progresses. This approach avoids the requirement for two different models being created on different software. ***QUEST*** also provides complete CAD capability to create and modify geometries or to import geometries from a wide range of CAD packages. 2D and 3D geometries can be saved and used in different models. Performance statistics can be displayed or sent to a file for use by other software packages.

Process Planning Summary

Digital Manufacturing is a sequence of Process Planning steps that de-construct product assemblies into the steps necessary to build them. Process Graphs summarize the sequence, reflect precedence requirements and report the time needed based on the constraints imposed. Initial schematic diagrams are produced to show the "ideal" arrangement of resources, including machinery and shop-floor areas. Actual facility layouts and machinery locations are added, resulting in a manufacturing definition of the manufacturing process.

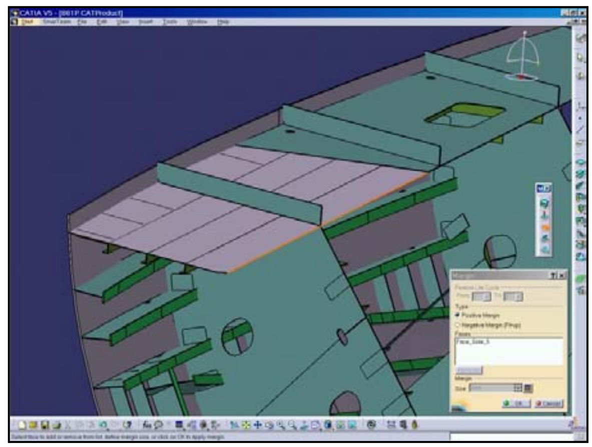


Time estimates and constraints (dates, equipment availability, etc.) are added, resulting in a highly structured database sufficient for discrete event simulation and task producibility simulations. A full digital manufacturing simulation identifies bottlenecks and allows process planners an empirical base to try "what if?" scenarios to secure additional time and cost improvements from alternative layouts, different machinery, alternative shop-floor layouts or even product redesign and modification. This planning has achieved high-level process optimization; the next step is to add manufacturing details and to validate that individual tasks can be performed as anticipated.

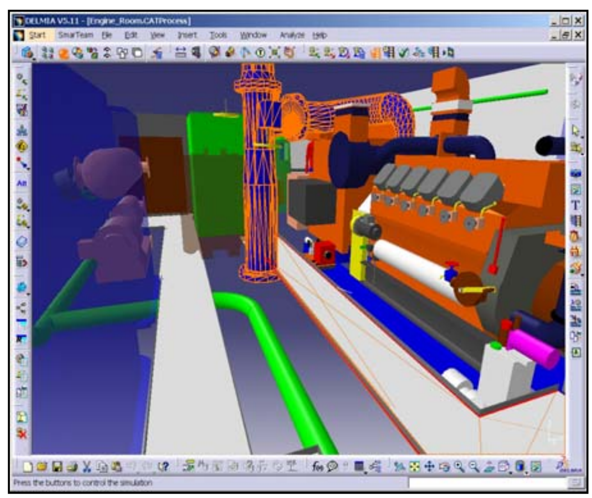
Process Detailing and Validation

Systems designers often experience situations where well thought-out design components cannot be easily manufactured, operated, or maintained once onboard the ship. While CATIA Digital Mockup tools provide part modeling, assembly and mechanism kinematics, DELMIA Digital Product Manufacturing (DPM) orchestrates inter-product relationships. DPM uses process detailing and validation tools to detect these problems early, allowing designers to reconsider their solutions before committing them to production.

Production Detailing, Part Motion, Collision and Clearance Detection



Much of shipbuilding involves the movement, positioning, fixturing and finishing (welding, painting, sand blasting) of heavy components. Positioning hoists and cranes, planning heavy lifts and pre-positioning plate stock for line heating or bending requires accurate positioning and tolerances.



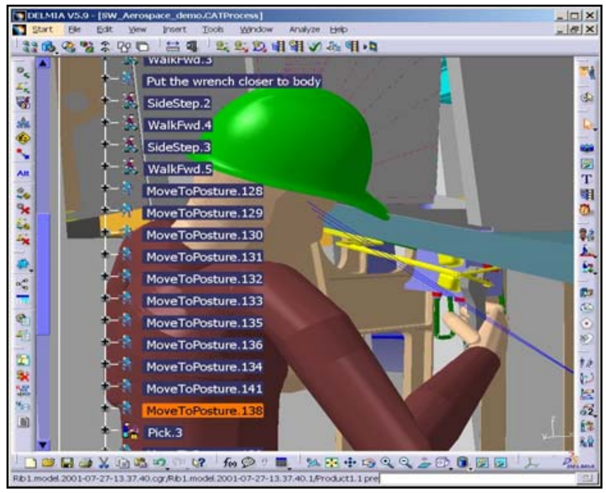
At the design level, great attention is paid to eliminating interferences in the completed fit-up of the ship. Design systems like CATIA use knowledge rules to solve the most difficult cases. Equipment must be operated, maintained and repaired, so these are prime considerations. However, at the manufacturing level, moving parts into their final position often is problematic and is highly dependent on sequence. The larger a sub-assembly becomes, the fewer positioning options there are. Motion studies, clash detection and clearances therefore become critical.

DPM Assembly workbenches analyze these dynamics (parts, sequences, time and motion) and ensure that the final positioning of all parts and sub-assemblies is possible. Simulation playbacks allow manufacturing and production engineers a digital medium to study and further optimize each step of the process. DPM Assembly is an effective way to analyze cycle times and develop animated scripts for training and work instruction preparation.

Resource Modeling and Simulation

The highest payoffs from Digital Manufacturing occur when overall processes can be optimized, tasks and non-value-added tasks eliminated, and resources including labor, shop-floor or machinery maximized with the shortest cycle times. Human factors and ergonomic analysis also can create a much safer workplace.

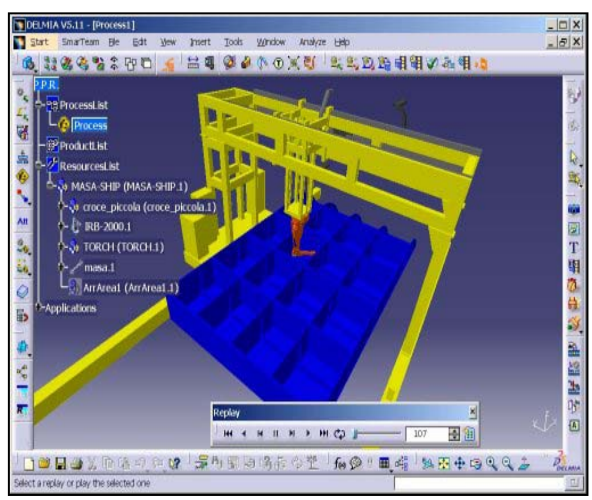
Human Simulation



In many production situations, work cell layout and ergonomics play critical roles. Human simulations are possible at every stage of design, manufacturing, installation, operations and maintenance. In early design phases, lines-of-sight play a key role in navigation bridge layout, while ergonomics are important to operating machinery or removing equipment. At the manufacturing level, workcell layout, access to sub-assembly areas, etc. are important. In extremely tight spaces such as a fan room, the ability of the human to accomplish the tasks required may have an impact on the design of the space.

Human models are considered resources in the PPR data model. The physical human attributes of manikins are defined and physical limits are set. These can be modified to reflect a specific population. The user assigns humans to a process as resources. Workbench tools assist in building libraries and in assigning human resources to tasks. This includes motion tracks, all of the body motions necessary to carry out a task. Timed motion and operations sequences provide excellent scheduling and labor cost data.

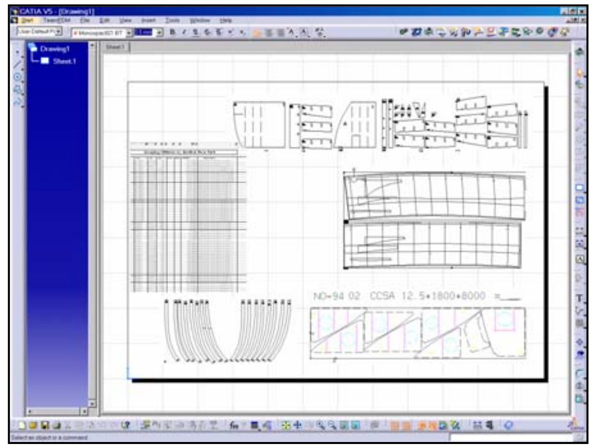
Yards with Human Simulation capabilities analyze horizontal and vertical reach and fields of vision. In extreme operating environments such as submarines or tight machinery spaces, this analysis is invaluable. On the shop floor, workstation design, tool and part accessibility, placement of scaffolding and safety fences, access to fixtures and robots and machine controllers can be simulated as well.



Robotic Simulation

Shipyards today are placing great emphasis on yard automation. The economics of shipbuilding demand greater standardization, modular design and consistent project-to-project practice. Some yards have achieved significant automation levels in their panel lines, flame cutting and pipe spool bending processes. Digital Manufacturing addresses these needs in two ways: simulation involving specific equipment like cranes, robots or NC machines, and general throughput simulation in which several operations, like nesting and flame-cutting, take place.

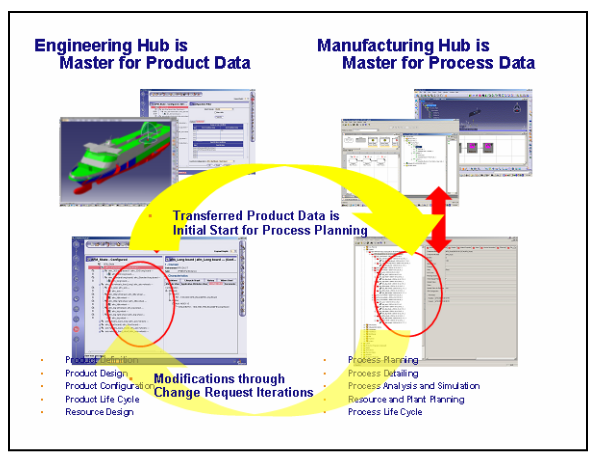
Manufacturing Data and Work Instructions



Numerous documents are needed before manufacturing can begin. The work content of jobs, manufacturing Bills-of-Material and 3D electronic work instructions (EWI) must be generated and organized by the jobs that will be scheduled and released to production. In addition, further refinements to the product data model are required.

Manufacturing features such as bevels, root-gaps, temporary lifting and support pads all need to be added to parts and assemblies to accommodate the welding process, crane lifts, fixtures, jigs and pin frames. The fully integrated Engineering and Manufacturing Hubs in IBM PLM play a critical role.

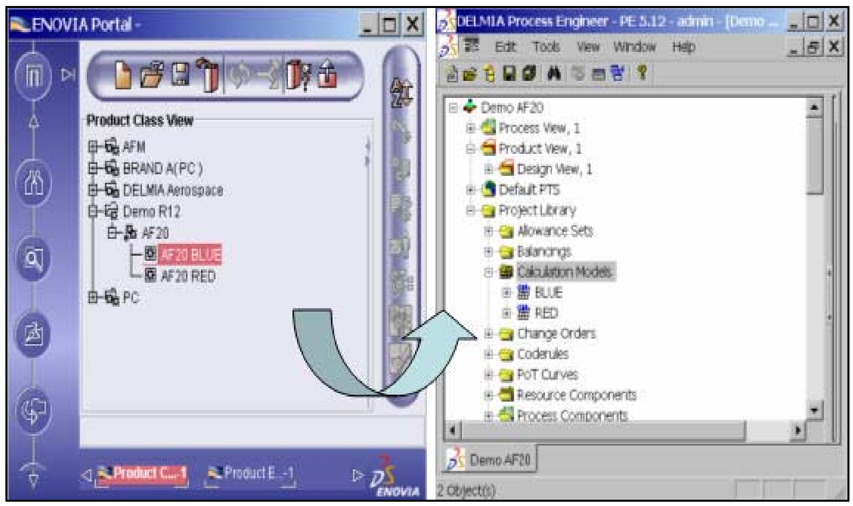
Manufacturing and Engineering Hub Connections



Each step of the Digital Manufacturing process relies on tight coupling between the Manufacturing and Engineering Hubs within IBM PLM. Here we will take a closer look at how the database architecture supports process planning, detailing and validation, as well as the extraction of manufacturing documents.

The Manufacturing Hub is the common manufacturing knowledge database shared by advanced planning, planners, manufacturing engineers, industrial engineers, robot programmers, NC programmers, Coordinate Measuring Machines (CMM inspection machines), programmers, facility layout, ergonomic specialists, safety engineers and production control. The Manufacturing Hub is the master database for Process Data and maintains the relationships between each manufacturing operation and the product data used in that operation, as well as the resources used to perform that operation. In addition, it contains a library of best practices that can be reused to ensure consistent manufacturing processes and quality. Design and manufacturing requirements and/or specifications can be "consumed" by manufacturing or inspection processes.

The Engineering Hub is the product "as designed," often referred to as the Engineering Bills of Material (EBOM) plus the CAD model for each part. As such, it is the master for all product data, geometry, object relationships and part-product structures. It also tracks attributes and effectivities that may be present, some of which are important for manufacturing. Product authoring is the primary role of the CATIA solution set.



The linkage between the Engineering and Manufacturing Hubs takes place through ENOVIA LCA client functions. Client services control data exchanges and maintain security. They also maintain all the links needed between components in the database, as well as the multiple views needed to support the workbenches just reviewed. The Engineering Hub typically includes product structures, parts lists, configurations/specifications, effectivities and geometry and provides access to Math Data in CATIA.

ENOVIA synchronizes product data in VPM V5 with the references to product data in the Manufacturing Hub; maintains links to the part, assembly, model, document, configuration, hull number, effectivities, annotations, tolerance information, maturity, geometrty cache; and math data, such as accurate measurement of the solids; and provides configuration identification for processing a portion of the ship in the Digital Manufacturing environment.

A typical sequence might begin with a Process Engineer. The user selects data from the ENOVIA LCA-maintained Engineering Hub. The user is given a custom view of the project structure (a project administration feature of ENOVIA) maintained by the Engineering Hub. The user further refines the product structure selection and ENOVIA responds by creating the necessary links to the DELMIA Process Engineer Client. The user then has access to the product data of the parts, product structure of the assemblies, configuration, effectivity, maturity, product attributes and both the CATIA model and a geometric representation. In terms of effectivity, ENOVIA maintained attributes that are relevant for manufacturing, linked to the Manufacturing Hub attributes.

Process Engineer clients use filters to create the links for particular product configurations in the Engineering Hub. The linkage is accomplished in steps: 1) display the available configurations in the Engineering Hub; 2) send the linkages to the Manufacturing Hub; 3) display the unfiltered and filtered project to the Process Engineer client; and 4) show and compare the filtered project in DELMIA.

Process Engineer offers search functions based on the updated status of entities in the project database and allows the user a way to determine if parts are new or updated. It also displays different icons for updated parts. During Detailed Planning, Process Engineers have the model math data available to take measurements when dimensions may not be available.

Hub Architecture, Data & Facilities

The IBM PLM Shipbuilding Vision has been described at two levels so far – the planning process involved in Digital Manufacturing and the relationship between the Engineering and Manufacturing Hubs that maintain all product, process and resource data. Here we review the architecture and bring both visions together.

Core Components

The primary data contained in the Manufacturing Hub are:

Process operations (fabrication, construction, outfitting, testing etc.) and process attributes;
Process operations linked to the Product Data (part geometry, attributes, EBOM, MBOM, LBOM[1], etc.) for the components or assemblies used in each operation; and
Process operations linked to the Resource Data (jigs, welding machines, labor classification, forklift trucks, user attributes, etc.) utilized in each operation.

The logical data model for product, process and resources is hierarchical. Products include ships, grand blocks, sub-assemblies, grouped machinery, panels or individual plates. Processes include fabrication, construction, outfitting or testing. Resources are machinery, materials transport, cranes, labor classifications and the yard's waterfront.

Workbenches like Process Engineer, QUEST, DPM for Assembly or DELMIA Human access the Manufacturing Hub to manage:

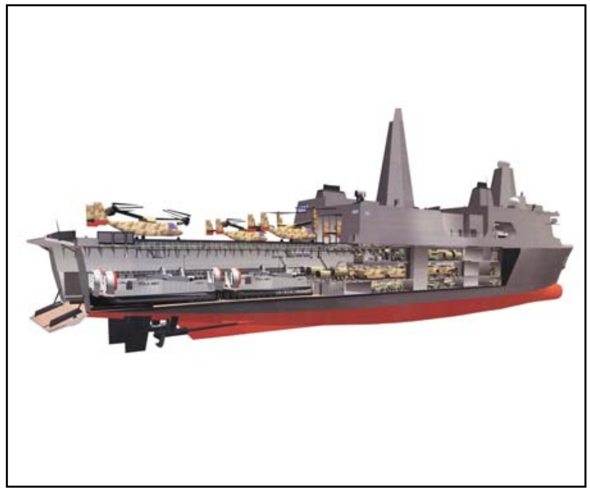
- Knowledge for re-use: Detailed processes with links to resources such as labor classification and required equipment (weld process linked to welder and welding machine) can be cataloged and reused;
- Constraints/rules in knowledge base are linked to applicable PPR objects in the database. For example, this class of weld requires pre-heating or this process should be completed before blast and paint;
- Time and sequences: Sequence of operations/precedence or Pert/Gant chart visualizations; and
- Work balancing to balance labor resources for optimal craft labor utilization.

[1] EBOM-Engineering Bill of Material, MBOM-Manufacturing Bill of Material, LBOM-Logistical Bill of Material

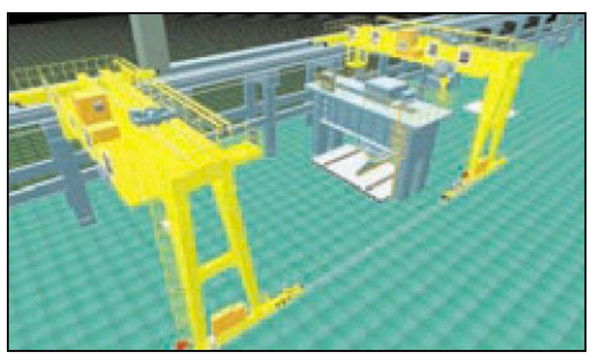
Implementations in Shipyards

With an overall vision for digital manufacturing established, how are shipyards using this technology today and what future applications are envisioned? Here we provide a series of short vignettes on IBM PLM implementations at a number of yards. Most are in their initial phases of setup. A few have reached mature implementations.

Design for Assembly, Design for Supportability, LPD-17[2]



The LPD 17 (Loading Dock Platform) class of transport dock ships represents the future of the Navy and Marine Corp's amphibious warfare. The LPDs must be able to carry 700 marines along with all the equipment needed to to fight, whether the assault is by helicopters, landing craft, amphibious vehicles, or any combination of these. Each vessel is 684 ft. long and 105 ft. wide in beam, drawing 23 ft. of water. Weighing 23,000 tons, it will take four diesels to drive the ships at up to 21 knots. The LPD 17 is an unprecedented modeling and simulation effort. The LPD 17 USS San Antonio is the first surface ship to every be designed in "Virtual Reality" Traditional practices started production with only 20-30% the design complete. Fast-track time gains were at the expense of rework later on. With DELMIA simulation tools, the design was 80% complete before any steel was cut. DELMIA visualization tools allowed broad-based collaboration and for design team to clearly see the work being done at each stage. The same system allowed a new level of communication between members where engineering changes were widely distributed and quickly reviewed. DELMIA's process planning and digital manufacturing tools modeled the production process. Engineers could study and optimize multiple assembly/disassembly process scenarios at each design stage. On the LPD 17 project, no steel was cut or welded until every step had been proven by simulation thus avoiding rework, cut apart and reweld.



Samsung Heavy Industries (SHI) is optimizing panel line production with QUEST. It is being implemented to develop a next-generation digital shipbuilding system integrated with industry best practices. The digital shipbuilding system is simulated to optimize the entire shipbuilding lifecycle process in a virtual environment. This project has received attention as a

[2] from <u>DELMIA simulation tools key to collaboration in building 21st century assult ships</u>, Troy, MI: DELMIA Corp., WORLD NEWS No. 5, July 2002, pp.11-12

landmark for process innovation in traditional shipbuilding. SHI plans to invest over three years. By the end of 2004 the project is expected to make significant contributions in cost reduction and improved quality through more streamlined and automated manufacturing processes.

Production plan optimizes production at BIW for LPD-17

DELMIA Digital Manufacturing software products were used to visualize the conceptual designs of shipboard systems, structures and human considerations concerning functionality. ENVISION allowed LPD17 designers to create their own geometry concept files or to import CAD files to evaluate the arrangement of critical facilities on the ship. Using digital mock-up capabilities, the design of the ship took place in a team environment, with different groups participating in the arrangement of each zone of the ship. Teams reviewed each zone from the perspective of engineering design review, milestone reviews, production planning, kinematic/ergonomic studies and physics-based studies. Assembly sequence plans were developed and a digital shipyard model of Bath Iron Work's waterfront -- including buildings, roadway layouts, railway layouts, cranes, equipment, floating dry-dock transporters and other heavy machinery -- was built. The digital model is used to detect collisions and ensure that ship components will fit into facilities. The model also helps planners determine how long it will take to move blocks and sub-assemblies to their proper positions for final assembly. Virtual forklift technology implemented for the LPD17 program is directly applicable with these models as well. Thus, BIW realizes project-to-project carryover of its modeling and simulation resources.

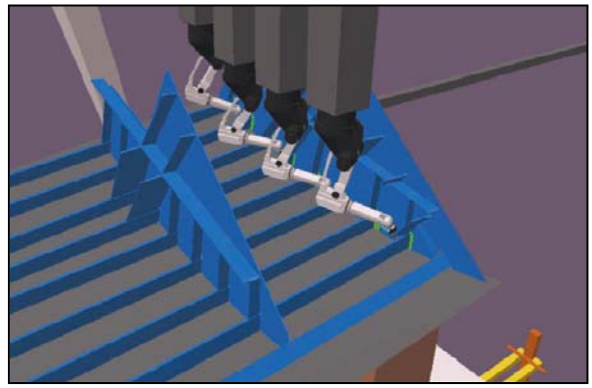
Building a standard design at multiple yards – DD(X) stealth destroyer project[3]

The Gulf Coast Regional Maritime Technology Center (GCRMTC) at the University of New Orleans, with sponsorship from the US Office of Naval Research, uses IBM PLM Digital Manufacturing techniques to research ways to streamline the shipbuilding process for the US Navy's 21st Century DD(X) stealth destoyer project. Researchers and production specialists evaluate design for manufacturing, define high-level processes and sequences, build libraries of best practices

[3] Gregory T. Dobson, DD(X) Manufacturing Process Modeling Technology, 2002

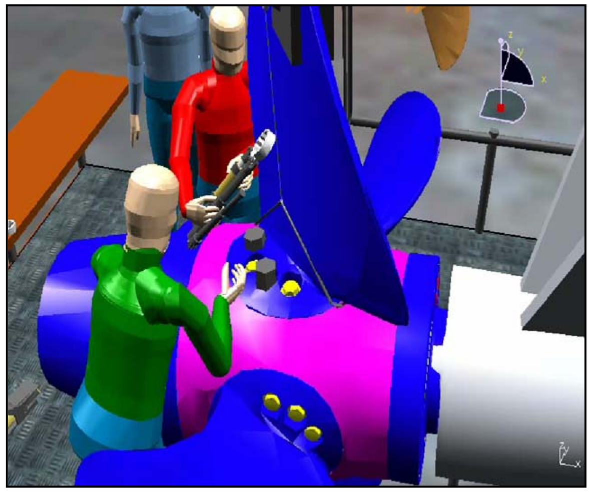
and analyze processes that effect capacity, flow, cost and value-added. Research involves creating PBOMs for MRP systems, and work order content for MES systems. The goal is to reduce production costs and effort, production planning time, the number of production reworks and the time/effort for performing production M&S. Participating DD(X) alliance yards want to increase reuse of models and simulations, evaluate the impact of changes, assess early designs for production and test new manufacturing processes.

Off-line programming of welding robots at Fincantieri and NGSS



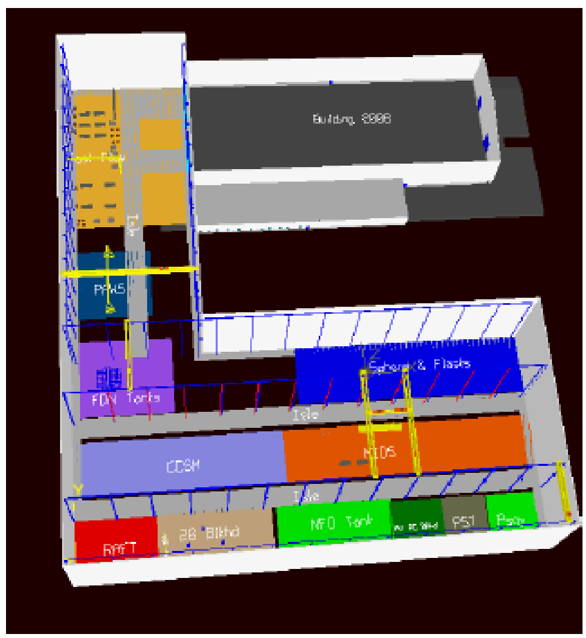
Fincantieri Shipyards S.p.A., Monfalcone, Italy, specializes in cruise and merchant ship construction. Welding stations at the Monfalcone shipyards include large, multi-axis gantry systems provided by Motoman and IGM. The gantry systems support either two or four robots during the welding of large block sections. Traditionally, shipbuilding is plagued with small weld batches as no two ships are identical, nor are any two ship sections alike. Each section typically requires a unique program with robots that take up to eight hours or more to weld a single ship section. To improve turnaround times, reduce piece-work costs and ensure consistent quality from block to block, Fincantieri invested in new robot systems and off-line programs using UltraArc PC-based packages. Working with Fincantieri, DELMIA developed an Arc Welding Macro Programming system called AMP. AMP groups common weld types in ship construction into families, each with a specification and standards template. Fincantieri uses UltraArc to systematize the process of robot programming and to retain the knowledge and processes from one hull to the next. UltraArc and companion AMP templates allow Fincantieri to achieve 100% offline programming – no touchups are needed and all robot process data are downloaded, including weld parameters. This enables the robot to maintain constant production. Welding process knowledge is now retained and transferred from one project to the next.

ISSELNORD maintenance training[4]



ISSELNORD, technical engineering service company based in Italy, is researching the application of advanced simulation and virtual reality to ship maintenance. Initial assessments were made of replacing a ship's propeller blades. Models were prepared of the propeller assembly, surrounding hull form, and the dry dock area where work is performed. Except in cases of damage, propeller blades would only be disassembled in hydraulic and internal mechanical system maintenance procedures. This task involves a team of five or six people working for approximately half a day. The propeller blades are very heavy, requiring special lifting procedures. In addition, the propeller blades are attached using tools that exert extremely high pressure. Understandably, for a procedure of this complexity, rigorous directives and highly defined procedures must be followed. DELMIA DPM holds all the physics-based information needed to run such a multifaceted model. The world-class cruise ship builder, Fincantieri, sees the potential for application of this technology at its yard. Development at ISSELNORD was supported by the DELMIA team of Turin, Italy.

Design / Build using Digital Assembly analysis at General Dynamics Electric Boat [5]



Digital manufacturing simulation at many yards focuses on improving processes like material flow, panel lines, block assembly, unit erection or dry-dock operations. Electric Boat has used a product-centric approach with the goal of defining manageable families of products and designing a facility to ensure that the resources required by these products are readily available during their fabrication.

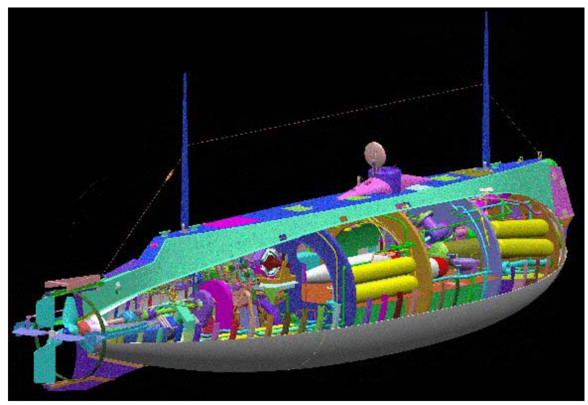
Electric Boat developed process models for various product families for next-generation submarine production. These process models provide critical input to the design teams as they determine space, equipment and manpower requirements for new yard

[4] from DELMIA World News, "Virtual Health and Safety Could be the Answer for Infrequent Tasks", Troy, MI: article, Virtual Manufacturing for Real Savings column, DELMIA World News No. 7, September-October 2003.

[5] from "Shipbuilding Facility Planning and Design: A Product-Centric Appproach", paper by Mark T. Traband et. al. NSRP Conference, undated.

facilities. Products were sorted into different families based on their characteristics, such as plate thickness, weight, fitting/welding rations, fixture requirements, welding/preheat requirements, piping complexity, and machining, inspection and pressure-testing requirements. Approximately 100 products were identified as candidates for assembly in the new structural fabrication facility. Spheres and flasks, foundation tanks, bulkheads, decks, large and small foundations and tanks are among them. DPM Assembly and CATIA CAD models were used as a starting point for simulation of manufacturing processes. Detailed process models -- down to the individual part assembly level --were created for foundation tanks, bulkheads, spheres and decks. A number of process improvements were realized, reducing non-value added time and overall production time for components modeled. The resulting facility layout provided numerous advantages over current production facilities at Electric Boat. Additional work is being done on the actual design of product cells, including the location of electrical and gas services, power supplies and part staging.

Digital Reconstruction of Naval History[6]



In 1896, the Holland VI became the first commercially successful submarine when its design was adopted by many navies of the world. Its inventor, John P. Holland, developed innovative solutions for diving, ballast and trim, navigation (dive and rudder planes), dual propulsion (electric/gasoline) and weapons, including torpedoes and a dynamite gun. A 3D digital reconstruction of 1,300 major parts, accomplished with CATIA, was analyzed by DELMIA DPM to simulate operation of all equipment onboard, including torpedo launching and reloading, submerging and the three modes of propulsion plant operation. Construction sequences and analysis were carried out to identify the most labor- and equipment-intense tasks.

DELMIA Human was used to determine how long it takes for a man to get into position to close a valve, pull a lever and change electrical panel configurations with blade switches. If there were plenty of space, it would be a simple matter to estimate the time with reasonable accuracy. But the *Holland* was a cramped environment and these studies were invaluable in determining the sequence of operations the crew had to take to operate and maintain the submarine. This project was a joint implementation of Electric Boat, IBM and Dassault Systèmes. All models courtesy of General Dynamics Electric Boat.

[6] from Edward Popko, Gary McCue, The Holland Project – Digital Reconstruction of Naval History, Poughkeepsie, NY: white paper and interactive compact disk, second edition June 2003.

Summary

The linkage in IBM PLM between the Engineering Hub and the Manufacturing Hub is the critical bridge between digital design and Digital Manufacturing. Digital Manufacturing solutions using the Manufacturing Hub database leverage the 3D design data in the Engineering Hub in manufacturing. This enables the shipbuilder to “build” the ship in the digital environment before executing it in the physical environment. This gives the shipbuilder an opportunity to perform a large number of iterations in the digital environment without a physical mockup. This can be used both to optimize manufacturing processes and to react quickly to unplanned events in the yard. Digital Manufacturing, built on the data in the Manufacturing Hub, is the next frontier for integrating design, manufacturing and production execution.

Conclusions

Advanced yards are re-examining their manufacturing processes to reduce time-to-market, improve quality and eliminate the costs associated with rework. Digital Manufacturing technology has already been proven in automotive and aircraft manufacturing and is now being successfully applied in shipyards worldwide. Initial benefits leveraging the IBM PLM digital manufacturing solutions have been obtained within the General Dynamics Marine Group at Bath Iron Works, Electric Boat and NASSCO; Northrop Grumman Ship Systems and Northrop Grumman Newport News; ISSELNORD; Fincantieri; and most recently at Samsung Heavy Industries.

Appendix A – Abbreviations & Acronyms

BOM – Bill of Material

CAA – CATIA Application Architecture

CAD – Computer Aided Design

CAE – Computer Aided Engineering

CAM – Computer Aided Manufacturing

CATIA – Computer Aided Three-dimensional Interactive Application

CAx – Computer Aided Technologies, includes CAD, CAM, CAE, etc.

CGR – Computer Graphics Representation

CIM – Computer Integrated Manufacturing

CM – Configuration Management

CMM – Coordinate Measuring Machine

CRM – Customer Relationship Management

DFP – Design for Production (ICCAS conference concept)

DPM – Digital Product Manufacturing

EBOM – Engineering Bill of Material

ERP – Enterprise Resource Planning

EWI – Electronic Work Instruction

LCA – Lifecycle Application

LBOM – Logistical Bill of Material

MBOM – Manufacturing Bill of Material

MES – Manufacturing Execution System

MRP – Materials Resource Planning

NC – Numeric Control

PBOM – Process Bill of Material

PDM – Product Data Management

PLM – IBM Product Lifecycle Management

PM – Program / Project Management

PPR – Product Process Resource

SCM – Supply Chain Management

WBS – Work Breakdown Structure

WF – Workflow

WP – Work Package

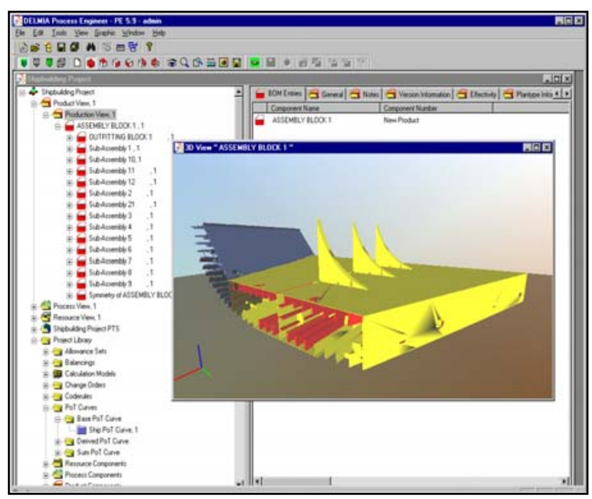
Appendix B – Digital Manufacturing Solutions

This section provides abstracts of the main DELMIA offerings that have been referenced in this paper. DELMIA solutions focus on the processes and resources needed for manufacturing and integrating shipboard systems and structural blocks. Typically these products and assemblies are defined in CATIA by one or more of the solutions described elsewhere.

DELMIA software solutions provide digital manufacturing and simulation support from concept design through manufacturing execution. They support production planning, facility layout, process verification, time and cost estimating, human factors and process flow analysis. The key benefits of using DELMIA for Digital Manufacturing are:

- A centralized, organized manufacturing information repository called the Manufacturing Hub, which can be shared by planners, estimators, manufacturing engineers, industrial engineers, lofters and health and safety engineers.
- Elimination of unbuildable situations and the resultant engineering change orders and first-time quality problems.
- Increased productivity from using the 3D, model-based environment for Design-for-Manufacturing and Design-for-Assembly activities.
- Minimization of efforts to accommodate unplanned events by leveraging the easy-to-use, high-level, model-based process planning of DELMIA with linkages to current design engineering data.
- Ability to do “what-if?” scenarios and understand dynamic relationships between design, layout and production systems behavior.

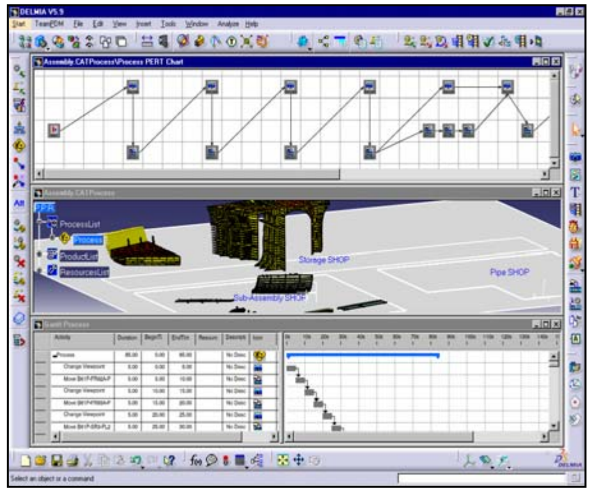
Process Engineer



DELMIA ***Process Engineer*** enables the user to define, develop and analyze alternative approaches to the manufacturing process. It provides the user with the ability to easily organize and visualize relevant planning data. The ***Process and Resource Planning*** module is used to generate a process graph of the sequence of operations and then to automatically generate a manufacturing concept.

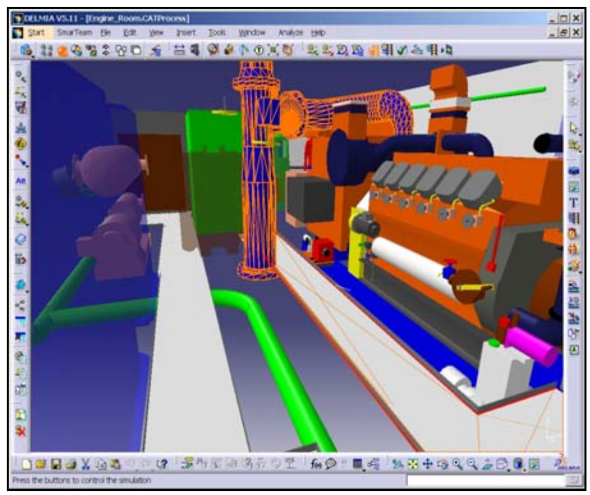
Based on internationally established methods for time measurement, the ***Standard Time Measurement*** module delivers a detailed process description for both manual and semi-automated manufacturing processes. It determines the required standard times and thoroughly documents them. The ***Product Evaluation*** module enables the user to filter specific product configurations and evaluate the cost of the proposed production plan versus the cost targets.

For the communication and sharing of information across the enterprise, DELMIA offers the ***PPR Navigator for Manufacturing*** module for accessing all the manufacturing data. All ***Process Design and Analysis*** modules are based on one Product, Process and Resource (PPR) data model, the ***Manufacturing Hub***. This allows users to share the same data among the different locations, departments and disciplines throughout the enterprise and across the supply chain.

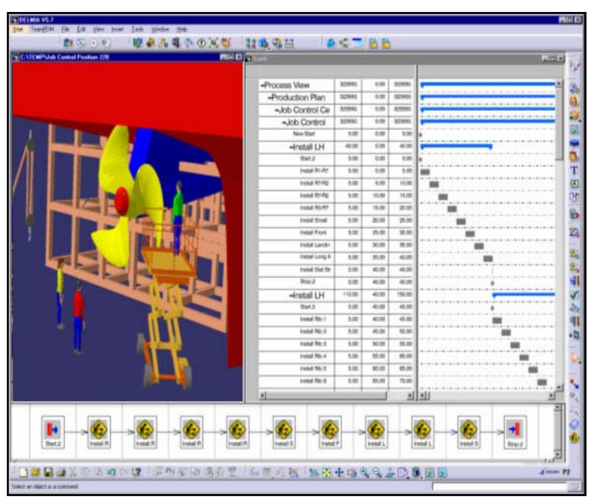


DPM Assembly

DELMIA ***DPM Assembly*** is used to develop more detailed process plans based on the geometry created in CATIA and other CAD systems. Product, Process and Resource information is all directly retrievable from the ***Manufacturing Hub*** database. ***DPM Assembly*** is used to determine the correct assembly process for the products and provides the user with the ability to evaluate alternative jig and fixturing approaches for the assembly sequence.



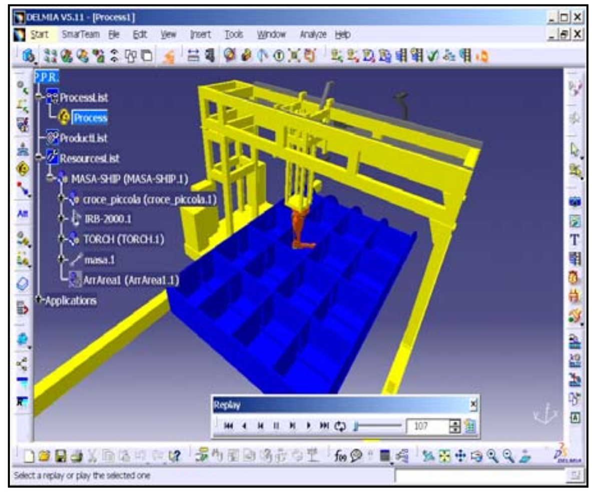
The collision detection capability of ***DPM Assembly***, and its ability to manipulate individual parts and subassemblies along their assembly paths, gives the user the ability to quickly conceptualize and verify alternative assembly sequences. The in-process states of the components are automatically generated for each process step and can be used to support Electronic Work Instructions (EWI).



DPM Assembly provides a Gantt- and Pert-charting interface, giving the user an easy-to-use method of developing the sequence of operations, timing and dependencies. ***DPM Assembly*** also is particularly useful in validating production and maintenance scenarios. Collision detection and kinematic capabilities verify that sequences are possible and within limits of tooling or transports like cranes, hoists or positioning fixtures. Electronic work instructions (EWIs) for shop personnel and maintenance crews can be automatically generated with a single mouse click, executing a customizable Visual Basic script. These EWIs can be created in html or xml formats with embedded hyper-links, providing the user with easy navigation of the required process step and support information.

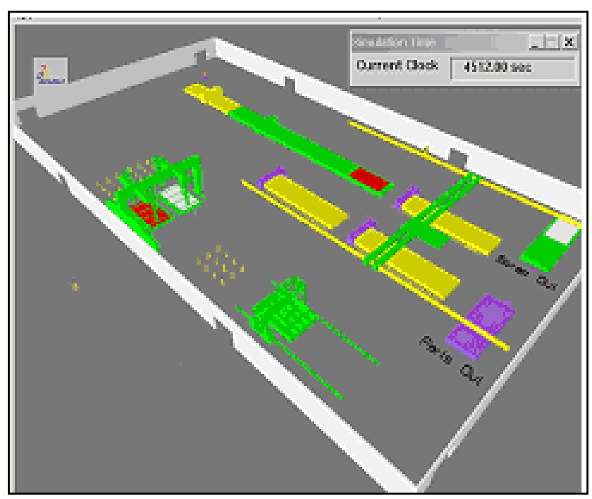
Process Engineer and ***DPM Assembly*** generate the process and resource information in the ***Manufacturing Hub***, which makes it possible to generate a ***QUEST*** discrete event factory model of the process flow.

Workcell Layout & Simulation



DELMIA ***Workcell Layout & Simulation*** products are kinematic simulation tools for design and evaluation of automated equipment and off-line programming of robotic workcells. Incorporating real-world robotic and peripheral equipment, motion attributes, kinematics, and I/O logic, **Workcell Layout & Simulation** products generate extremely accurate simulations and provide the ability to optimize robot locations, motions and cycle times. This helps users eliminate costly collisions between robots, parts, tools, fixtures and surroundings. Kinematic devices defined in the ***DMU Kinematics*** module (available in both CATIA and ENOVIA) are directly importable into ***Workcell Layout & Simulation****.* This application includes Gantt- and Pert-charting capabilities, which provide the user with an easy method for generating the interactive functionality of workcell devices when developing simulation scenarios of a manufacturing process scenario.

QUEST – Discrete Event Simulation

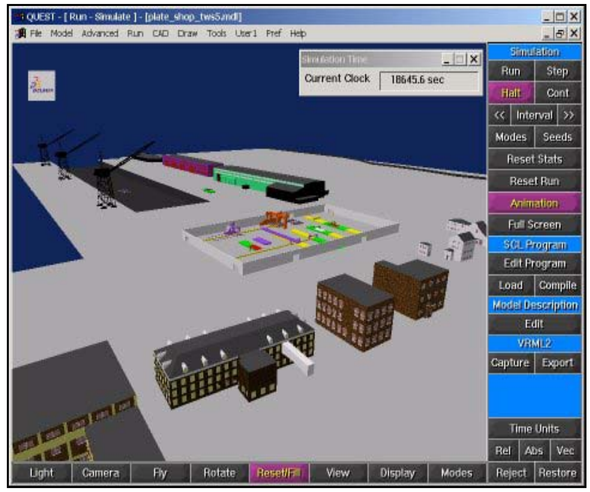


DELMIA ***QUEST*** supports discrete event simulation and is a combined analysis and visualization workbench providing stochastic analysis of the combined probabilities of all events in the process flow. This provides a realistic prediction of the throughput of the shops and flow time through the shops while identifying bottlenecks and generating reports on asset utilization.

Through a high-level simulation language, users define custom behaviors of movements for process machines, humans and materials. Sequences between dependent steps of manufacturing can be linked together to validate and visualize the impact of process flow decisions or the startup of a process.

QUEST provides tools for simulation programming, process flow analysis, statistics capture and reporting, as well as visualizations. ***QUEST*** allows models to be transferred from the 2D world into the 3D world. In this way, the model can start off at a simple conceptual level of detail and then evolve as the design process progresses. This approach avoids the requirement for two different models being created on different software. ***QUEST*** also provides complete CAD capability to create and modify geometries or to import geometries from a wide range of CAD packages.

2D and 3D geometries can be saved and used in different models. Performance statistics can be displayed or sent to a file for use by other software packages. A wide range of standard reports are available and customized reports can be easily created.



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