A Production Control System Based on Earned Value Concepts

Ramón de la Fuente1 and Ernesto Manzanares

In the past four years, Astilleros Españoles S.A. (AESA) has completed the implementation of its shipbuilding industrial model, based on the use of a product work breakdown structure (PWBS) for each new construction shipyard. As a logical development of this model, a new production control system has been built using earned value techniques. This paper describes the state of the implementation of this production control system. First, the basic structures of the shipbuilding model are defined as the product work breakdown structure of each ship under construction, the process breakdown structure of the shipyard, and the organizational breakdown structure. Also described is how these structures are reflected in the basic logical concepts of the production control system: product, process, organization, control accounts and control points (by product, process or organization), work packages and work orders. The functional description of the production control system is explained. Some examples of outputs are presented, stressing the method of result analysis prepared for each responsibility level of the shipyard—general manager, production manager, and shop and production unit managers. Next, the development of the implementation phase in one test corporate shipyard is described, as well as the main problems found and the way in which they have been solved. Finally, some conclusions about the production control system are presented, together with several future planned developments for the system.

Nomenclature

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Explanation</th>
</tr>
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<tbody>
<tr>
<td>ACWP</td>
<td>actual cost of work performed</td>
</tr>
<tr>
<td>AESA</td>
<td>Astilleros Españoles S.A.</td>
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<tr>
<td>BAC</td>
<td>budget at completion</td>
</tr>
<tr>
<td>BCWP</td>
<td>budgeted cost of work performed</td>
</tr>
<tr>
<td>BCWS</td>
<td>budgeted cost of work scheduled</td>
</tr>
<tr>
<td>CCA</td>
<td>cost control account</td>
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<tr>
<td>CPI</td>
<td>cost performance index</td>
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<tr>
<td>CSC</td>
<td>cost, schedule and control system</td>
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<tr>
<td>EAC</td>
<td>estimate at completion</td>
</tr>
<tr>
<td>IEAC</td>
<td>independent estimate at completion</td>
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<tr>
<td>NSRP</td>
<td>National Shipbuilding Research Program</td>
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<tr>
<td>OBS</td>
<td>organizational breakdown structure</td>
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<td>PAM</td>
<td>process assignment matrix</td>
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<td>PBS</td>
<td>process breakdown structure</td>
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<tr>
<td>PIMET</td>
<td>Plan Integral de Mejoras en Tecnologia (Integrated Technology Improvement Plan)</td>
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<td>POAM</td>
<td>product assignment matrix</td>
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<td>PWBS</td>
<td>product work breakdown structure</td>
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<td>TCPI</td>
<td>to complete performance index</td>
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<td>WO</td>
<td>work order</td>
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<td>WP</td>
<td>work package</td>
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Introduction

In the past four years, an important effort has been completed to design, develop and implement a shipbuilding industrial model based on the use of zone and stage production technology, flexible production planning and scheduling, and product-oriented breakdown structure. As a necessary development for this industrial model, a specific project was started with the target to design and implement a new production control system based on the application of these related techniques and the use of earned value concepts.

For this purpose, a specific team was created which assumes as its basic target the modification of the conventional “activity” concept to the new “product” concept.

This team, in connection with the factory production team, developed a new production organization process based on the use of such interim products as planning and scheduling units. Each interim product takes the place of an old activity planning element, and introduces a new relationship between the three basic elements related to the production frame:

- product, as the element to be done,
- process, as the way to produce using group technology rules, and
- organization, as a specific group in charge of getting the product finished.

The second basic concept, earned value, introduces a complementary innovation on the conventional production control, in the fact that the production progress is measured by the individual progress of each product scheduled. Earned value concepts and methods are not described, since they are well known and enough bibliography exists on them. What is shown is their practical application to new construction control in shipbuilding.

The use of group technology concepts allows, besides a better industrial production performance, a more accurate estimation of future results, based on actual performances for each considered group. The relationship between product, process and production units (organization) has been established under the rules of group technology.

The new production control system changes the old concept of “results measurement” to the new “production management,” providing continuous information on cost and schedule variations on each product, at each product level considered, and a complete analysis of production performance and productivity parameters.

This project is included in a larger Productivity and Competitiveness Improvement Project, which has its origin in the PIMET project (Plan Integral de Mejoras en Tecnologia or Integrated Technology Improvement Plan), performed during the past five years using some ideas from the National Shipbuilding Research Program (NSRP) and documentation.

Product-oriented work breakdown structure

It is not considered necessary to redefine the interim product concept, which has been very well established in the
In the beginning of the project, a product-oriented work breakdown structure (PWBS) was developed for a shuttle oil carrier that was being built in the test shipyard. Each finished element was defined as a "product," integrating steel and outfitting works whose integration with other products, or elemental components, produces a new and more complex product. Figure 1 shows this basic concept, which is applicable to any other ship.

Following this, any product at any level can be identified, and each of these products can be taken as the "control point," selecting the most convenient level in accordance to production control needs.

### Process breakdown structure

The following step was the production process identification and definition. Process is defined as the way to produce a specific product or element applying group technology concepts. Each shipyard has its own process flow, and its own process definition.

This process structure defines the shipyard production structure through the identification of their production processes, all characterized by group technology concepts.

The main characteristics considered in the process definition are that it be:
- group technology based,
- clearly identified, and
- stable in efficiency parameters.

Under these concepts, the process breakdown structure (PBS) of each shipyard has been developed, taking into account the functional differences, and the specificity of each of them. Figure 2 describes the basic scheme of these breakdown structures.

As an example of a third-level definition, technological family, Table 1 shows the considered technological family of the steel processes in the test shipyard.

A very simple numerical codification system has been used to easily identify processes. In general terms, to produce a specific product it is necessary to perform tasks belonging to several processes.

Each process is assigned one or several units directly related to the amount of work required to carry out the task. For instance, the numbers of thin and thick pipes are considered reasonable units for the estimation of work for an outfitting job (e.g., welding pipes of different thicknesses), that has been defined as a process at a certain level.
Organizational breakdown structure

The organizational breakdown structure (OBS) describes the structural organization of each factory, and shows the different responsibility levels. This is a typical OBS, and in general terms is the same for all corporate shipyards. Figure 3 shows a typical OBS of a shipyard.

In this structure production unit is defined as a workshop or a workshop part, with facilities and utilities especially arranged for one or more technological processes, with professionally trained workers, and with their own process specifications, production procedures, dimensional accuracy systems, quality procedures and controls.

Each production unit is specialized in one or more processes, and produces one or more types of interim products, under the most convenient production conditions, and with the best production performances. It is also possible for similar products to be made in two or more production units, with equal or similar processes, but normally the production performances are not equal.

Process assignment matrix

Crossing two basic structures, the process breakdown and the organizational breakdown structures, a process assignment matrix is obtained, defining for each production unit the processes that the unit performs. Another layer of the matrix defines production performances expected of each production unit and specific process.

To estimate the required man-hours for a given task, two steps are followed. First, the quantities of the chosen units are determined. Second, an expected efficiency for each unit of measurement at the production unit is applied. This efficiency is taken from previous experience of the yard, taking

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into account the procedural modifications to be made in each particular case.

This matrix enables one to plan the most convenient way to produce interim products or elements for each project in accordance with the work charge of the different workshops. It also provides an easy procedure to determine the differential costs derived from changes in the work assignments.

**Product assignment matrix**

The second matrix developed is the product assignment matrix, crossing the project product work breakdown structure with the process assignment matrix. The project PWBS shows, for each specific ship under construction, all interim products that must be done for this ship. Crossing this PWBS, for each one of the products, with the process matrix, it is possible to determine:

- what products will be made,
- what process will be applicable,
- what production unit will be in charge, and
- how much it will cost.

This matrix answers the four basic questions raised: What?, How?, Who?, and How much?

An example of this matrix is shown in Fig. 4. For this matrix it is possible to define all the control points, as well as to determine all the work packages.

**Work package**

The work package (WP) is defined as the amount of work of a process to be done by a production unit to obtain a product. That means that a finished product is the sum of different work packages, each work package belonging to a specific process and a production unit.

Using the two assignment matrices previously developed, it is possible to define the work packages for each product, taking into account the following basic rules:

- Each WP belongs only to a product.
- Each WP belongs only to a specific process.
—Each WP contains a predefined work content and its corresponding budget.
—Each WP must be scheduled.
—Each WP belongs only to a specific production unit and must have only one person in charge.
—The size and duration of each WP depends only on the characteristics of the work involved and the conveniences for its control.

Figure 5 shows a typical definition of work packages for a product. Also, Fig. 6 shows the code used in the test shipyard to describe each WP.

**Work order**

A work order (WO) is the interface of the system with the shop. A WO contains the technical description and the time frame for a specific task of a certain process to be performed by a production unit.

A work order is the lowest-level control element used in this production control system, and is the basic element in calculating performance and conducting the production process.

Some important characteristics to be considered when defining work orders are:
—A WO is a logical work unit, to be executed by a production unit in a practical and reliable manner.
—A WO must have a logical start and termination, because it is the basic measure for the progress of the project. When the order is completed there should not be any doubt as to the work accomplished. For this reason, the WO must be defined in utmost detail with reference to the work content and extent, including all corresponding technical infor-
A WO must have a short duration, normally no more than two weeks and a small work content, not more usually than 200 man-hours.

A WO must not be stopped when it has been started.

A WO must be done in the exact way that has been planned. If necessary changes must be made, it is better to cancel the WO and produce a modified new one.

Precision in defining work orders, as well as accuracy in capturing results, is the key for a reliable system, and a reliable estimation of final results.

This production control system has defined the following WO types:

- **Normal**, or typical, WO belongs to a unique WP. It is a part of the WP, with a clear definition of the tasks it includes, so that its completion is easily checked. All the tasks in the WO belong to the same process as the WP. This type of WO represents the majority of edited work orders.

- **Distributed** is one WO which belongs to two or more WPs, always made by the same production unit. Its use is restricted to WPs with small work contents whose individual control is difficult.

- **Service** is one WO corresponding to support works. The hours charged to these WOs are distributed among all the WOs that are being executed during their duration period.

Normal and distributed WOs may be subcontracted, and the program contains a specific module to deal with this situation.

Figure 7 shows the form used to define and edit WOs in the test shipyard.

There are three important criteria applied to the WO definition:

1. There should be, as a minimum, one work order for each work package.

2. The sum of WO budgets for each WP should be equal to the WP budget, including those distributed WOs related to the WP.

3. The sum of WO work contents for WP should also be equal to the WP work content, including the distributed WOs related to the WP. The schedule of a WO must also be coherent with the schedule of the WP (WPs, in case it is distributed) from which it is derived.

In summary, the WO represents an unmistakable work unit, which must be performed without disturbances, and under the supervision of a unique responsible person. As the WO has an identified work content, it must have a fixed budget and an integrated schedule.

**Cost control accounts**

Cost control accounts (CCAs) represent the visible expression of the control points, and allow the management of the
different project parts by the way that the project has been divided.

A CCA inside the system is defined by a certain selection of work packages, and different selections of WPs produce different types of CCAs. It is possible to sum up all the WPs belonging to a product, and have a CCA for a specific product, as for a process or for a production unit. The codification system for the WP, which includes characterization blocks for product, process or production unit, permits all the possibilities, and renders this system flexible and reliable.

**Functional structure of the program**

The program has been developed with modular organization concepts. In this way it has been possible to use some modules while others were in the development stage. In the paragraphs that follow modules are described in the generic order they are used when controlling a new construction project.

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**Project definition module**

The objective of this module is to allow a user to define a project. This definition includes the specification of the work to be performed (and of the required manpower), the departments responsible for it and its scheduled time distribution. The final product of this module is a performance measurement baseline that relates the accumulated manpower to be used with time. This baseline may consider the whole project, or may be built by product, process, organization or any combination of them.

In the terms described so far, it is possible to state that this module allows a user to specify for a project the interim products of the work breakdown structure, the process breakdown structure, the organizational breakdown structure, the process assignment matrix and, finally, the product assignment matrix.

While the project progresses, a more detailed knowledge is obtained about the work that is necessary for each interim
product. Typically, three situations are considered for the project. The first one has available the information that is generally known at the time a contract takes effect. The second situation considers the information at the time the building strategy is fixed and the third one has available all the information contained in the detailed design.

The specification of a project may be done at any of the situations referred to. The later in a project life the more detailed the information will be. Then, it is possible to build work, process and organizational breakdown structures, and process and product assignment matrices for each of these situations, although the level of detail will vary.

The monitoring of performance is carried out at the most detailed level in order to obtain maximum accuracy. However, it has been considered useful to include in the module the possibility of specifying the project at the initial levels, with two objectives:

- To distribute the budget entirely and have a global version of a project at any time, although with a smaller level of detail.

- To obtain performance estimates referring to the processes and units of measurements defined for the initial levels, once the final results are known. These performance ratios are used for estimates of future ships, thus feeding the estimation cycle with actual results.

The result of this module is a database containing the above-mentioned structures plus the work packages for each level of specification selected. The databases are related in such a way that, for a given product, it is always possible to compare the work packages obtained at different levels.

The product, process and organization structures are defined as hierarchical structures. There is a set of program utilities for the management of this kind of structure, allowing users to create or modify them with the minimum restrictions to assure their integrity.

Another set of utilities is provided for the management of the work packages. This allows users to create, modify, list, graph, etc. the work packages of every database. Also, it is possible to obtain numerical and graphical expressions of

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**Fig. 7** A sample form for work order definition

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<table>
<thead>
<tr>
<th>Work Order Schedule</th>
<th>Work Order Content</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Start</strong></td>
<td>UOM 1</td>
</tr>
<tr>
<td><strong>Finish</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Actual Start</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Actual Finish</strong></td>
<td></td>
</tr>
</tbody>
</table>

- | UNIT CODE | QUANTITY | TOTAL |
---|---|---|---|
- | | | |

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- To distribute the budget entirely and have a global version of a project at any time, although with a smaller level of detail.

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any performance baseline by process, product or organization.

Another utility of the module allows the handling of the management reserve. Exchanges between work packages and management reserve are possible in both ways, with all the necessary cautions to maintain the integrity of the system. It is possible to obtain detailed reports of the evolution of the management reserve, as well as of records showing the nature of all changes carried out.

The module allows the connection with the planning and schedule systems in some of the shipyards. However, a high degree of manual handling of work packages is still needed, for at present there is not a unified approach to planning in all the new construction shipyards using the system.

Work order issuing module

Work orders are the interface of the system to the shops. The production system of the shipyard does not need a knowledge of the product assignment matrix or of any of the structures used by the system. All work packages are broken down (or grouped) into work orders, which are issued to the shops approximately three weeks in advance of their scheduled beginning. It is up to the shops to prepare a detailed programming of their work with the orders they have received.

The normal WO module makes sure that each WO complies with the restrictions on the quantity of work imposed by the work package to which it is related. For distributed orders that belong to several work packages, the proportion of effort assigned to each work package is recorded, with a check on the suitability of the assigned workload.

The utilities included in the module allow easy handling of new or existing orders, including creation, modification, issue, opening and closure of work orders. The module offers users the possibility of customizing reports on work orders issued, or on work orders in various states of readiness, such as approved but not issued, pending approval, in process, due finished but delayed, or closed. It is possible to limit the scope of reports in the customary way to any pattern of the product, process and structure organizations. Furthermore, it is possible to obtain reports about the orders issued for each work package, thus allowing the controller to be aware at any time of the degree of fulfillment of a given work package.

Subcontracting module

The system has a specific treatment for subcontracted work orders. Normal and distributed work orders may be assigned to subcontractors. They are included in the system in every respect, although reports concerning these orders are kept separate from orders carried out in the same shipyard. It is possible to obtain a combined report on completed work and, once subcontracted orders are finished, to compare their costs with similar orders not subcontracted. The definition of the building strategy includes an estimate of the products or work packages that will be subcontracted during the project, but subcontracting is also decided “on the fly” to solve production problems that may arise. The system allows users to define work orders as subcontracted at any time (until actual hours are charged to the work order).

The issuing of subcontracted orders is similar to that of in-house orders, except that it is divided into several stages, due to the intervention of the purchasing department of the shipyard. The initial issue of a WO, with all technical details, is returned from the purchasing department with information regarding the external shop that has received the order, scheduled dates and contract cost. When the WO is completed and delivered back to the yard, its status becomes “closed” and new information about delivery date, inspection or transportation costs, etc., is added.

Subcontracted work orders may be carried out in the external suppliers’ shops or within the yard. In the former case, no hours are charged for shipyard services, such as movement or WO preparation, while in the latter case service hours are recorded and included in the cost of the WO.

Reports similar to those for in-house orders are available, plus some others regarding subcontractors by processes or delivery schedule.

System update module

The main program of the module is a batch program that is run at the end of each accounting period. Its aim is to keep the system abreast of actual costs incurred for all tasks currently being executed. Actual labor costs are retrieved from the standard personnel database of the shipyard. Daily information about the hours assigned to every work order by every worker is stored in this database.

The system does not require a fixed length for accounting periods. Nonetheless it is customary for the shipyards to update the system weekly. Some shipyards make slight changes to the accounting periods in order to have information about complete months.

The main functions carried out by the update module are:

- Integrity checking of the system, which may be called at any time interactively, allows users to analyze the data files retrieved from the personnel database to check inconsistencies between these files and the system database.
- Updating of the WO historical database with actual charged hours information for the latest accounting period.
- Apportionment of service hours to work orders currently being executed.
- Calculation of main values for each WP during the accounting period: budgeted cost of work scheduled (BCWS), budgeted cost of work performed (BCWP), actual cost of work performed (ACWP) and service costs.
- Historical WP database update.
- Update of cost performance index (CPI) values and estimates at completion (EAC) for each WP in the historical WP database.
- Update of historical databases for elements of the PWBS, PBS and OBS hierarchies.
- Revision and update of all historical databases, taking into account the subcontracting that occurred during the last accounting period.

The time taken to run the system update function depends largely on the amount of subcontracting during the latest accounting period, because this variable requires the revision of historical databases from the beginning of the project. Once this revision is carried out, the values for a WP and for any given time reflect the latest knowledge about the amount of work that has been subcontracted. An average updating time in an accounting period with large subcontracting and about 1500 work packages, 6000 work orders, with about 400 of them active, is about 1/2 hour. This timing has been obtained for the production control system running on a standard PC 486/66. Once the updating is over, reports are immediately available to any user over the network. It is normal to have printed reports reflecting changes that have occurred up to 24 hours before updating.

Reporting module

The reporting module can produce simple and powerful reports that describe the state of a project at any level of detail. The operation of the module has been designed as user-friendly as possible, for this is the only module used by most of the shops and production managers. The reports are offered in numerical and graphical form whenever possible.
Presently three types of reports are offered to users. **Cost and schedule reports (Figs. 8 and 9).** These reports allow a user a quick vision of the variables usual to CSC systems, as shown in the figures.

These values are shown for the last accounting period or for the last n periods, where n may be chosen by the user, with a maximum of six for reasons of space in the report (all of them are presented in A4 format). It is possible to obtain similar reports between two arbitrarily selected updating dates, grouping all the accounting periods between them. This utility allows users to analyze performance during a given period in a shop, for any desired process or interim product.

There is a degree of flexibility allowed to a user for customizing the report regarding the selection of the work packages whose values make up the report. The user is requested to decide the scope of the report using any combination of the elements of the product work breakdown structure, the process breakdown structure and the organizational breakdown structure. The selection process is organized using the hierarchical nature of these structures, and has been shown to be quickly comprehended by users with little or no computer experience. It is very easy to select the information regarding the whole project, a shop, all activities of a production group, some processes carried out by a specified production group, a whole process, a product, or a combination of products of a certain level.

Graphical reports are offered, in addition to numerical ones, covering the evolution of BCWS, BCWP and ACWP from the beginning of the project. Also the evolution of the CPI may be followed in a graph.

All reports are interactively obtained and may be followed on screen or copied on paper. Another property of the information obtained is that it is possible to obtain the reports for any given accounting period, not just for the current one. This possibility is explained by the exhaustive historical records that are kept for the state of the project at any date since its beginning. The only difference that may be found between the report for a previous accounting period (obtained at the time of that period) and the same report ob-
Fig. 9  A sample of one accounting period report by organization

tained at a later date is that it incorporates all information regarding subcontracting that has been generated after the accounting period ended.

Reports may be obtained for in-house work, for subcontracted work, or for a limited combination of both. Also, in the case of in-house work, it may be desired to incorporate the service hours to the budgeted cost and to the actual cost of work performed, or to obtain a report showing only the direct costs, without services.

**Productivity reports.** It is possible to obtain, at any time during a project or at its end, an estimate of the technical productivity rates that have been obtained during the project. Productivities are derived statistically using as observations the actual man-hours spent in every finished WO included in the desired selection by product or organization.

The productivity is obtained for a single process or a range of processes, and its scope is determined by a selection process very similar to that outlined for the previous reports, but containing only the PSN and the ORS. For instance, it tion unit; or selecting some of the products that contain the process it is desired to analyze.

As the system keeps complete historical records of the evolution of the project, it is possible to ask for reports about the productivity rates at the end of any accounting period, not necessarily the last one.

Once the project is finished, the same module is used to compute statistical estimates of the productivity rates in terms of the parameters used in the first- or second-level definition of a project. Those values may be used in future estimation of workload.

**Report of the work carried out in a period of time.** A functionality has been developed to obtain reports showing the hours charged during a certain period of time, selected by the user. The listings show how much effort has been dedicated during the selected period to a certain range of tasks. The information offered includes the following:

—WOs that received any charges during the period, scheduled and actual dates for these orders, man-hours charged
and actual dates for these packages, man-hours charged during the period and accumulated, status at the beginning and end of the period, percentage completed at beginning and end of period, cost and schedule variance.

—Similar information is provided for products that have received charges during the period.

The range of information may be selected by a process similar to that described for previous reports.

Auxiliary modules

A number of modules are necessary for the operation of the system, but add little from the theoretical point of view. Some of these are:

—Utility for backing-up and restoring information, based on those offered by the databases.

—Utility for initiating a database for a new project, with partial copy from a previous project.

—Security system, based on personal and departmental keys for all functions of the system.

—On-line help system.

The simple enumeration of these systems makes clear their function.

System implementation process

At the beginning of 1993, the technological development direction of the corporation was assigned the task of defining the theoretical basis of developing and implementing a production control system. It was a condition of the system to agree entirely with the new concepts of construction by zones and stages and group technology, recently integrated into the production system of the shipyards owned by the corporation.

The main aim of the assignment was to improve shipbuilding management, within a larger program of increasing the shipyards’ competitiveness.

From January to June 1993, all the theoretical bases of the system were developed, as well as the basic decomposition structures. The work was jointly carried out by the technological development direction and production teams from the main shipyards. One shipyard was chosen as the test facility.

The selected objective was the initial implementation of the system to control the building of a sophisticated 120,000 dwt shuttle tanker and a sister ship that was to follow. For this purpose, it was necessary to redefine the specification of the project according to the system theory, and accommodate all work packages and later work orders according to the same theory. A precondition of the work was to obtain all the information from the shipyard with the minimum disruption of the systems being used at the time. The objective was met adequately.

The analysis and programming of the computer program that was meant as the system support were begun simultaneously. A decision was made to produce the first implementation of the computer program on a PC. The idea was to use an inexpensive device, well known in the shipyards and user-friendly, which could be easily extended through a local network. The program was developed in a modular form, as has been described. Milestones in its development and implementation were as shown in Table 2.

From March 1994 the system has been regularly applied and it has already been used for three newbuildings, two shuttle tankers and a very large crude carrier (VLCC).

The system results are considered as official for control and personnel purposes in one of the shipyards since the beginning of September 1994 for steel processes and, from December 1994, for outfitting processes as well.

The conceptual basis and initial results of the system have been discussed with the managers from other corporate shipyards and the implementation schedule for these shipyards was started in September 1994.

The productivity module, containing estimation for future constructions, is in the test period and will come into normal use by November 1994.

Implementation

Implementation in the shipyard and real-life application have not been an easy task. Even with the full cooperation of the production team, it was necessary to overcome a number of difficulties, such as noted below.

Product identification and definition—The factory already used a product catalog in its production system. However, it was necessary to carry out a further clarification of existing products. The aim was to obtain suitable products for production control purposes, not too small for control operation, not too big and complex for a meaningful contents definition. This is a continuous effort that is being improved from ship to ship.

Process identification—A similar task was the identification and normalization of processes, according to group technology theory.

Organization definition—Initially the existing organizational structure of the factory was left unchanged, but experience in the system use is providing clues for its improvement.

Work documentation—The previous work documentation system has had to be adapted to the requirements for the new work orders. It was necessary to balance the need for more detailed documentation of the work orders to the shops with the increased manpower required to prepare them.

Personnel instruction—Another worthy task has been to persuade all foremen and workers of the importance of a correct assignment of spent hours to the actual work order. The reliability of this information is the cornerstone of the whole system of results monitoring.

This implementation process is being enhanced with the production of a system manual. It contains the operational aspects of the system, as well as its influence over the production organization. This manual will complement the program’s user manual, and on-line help.

Conclusions and planned developments

According to experience, the operation of the system briefly described in this paper has two main advantages:

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| Operational tests: |
| Initial tests | May - September, 1993 |
| Pilot application | September, 1993-July, 1994 |
—Swift and ad-hoc information, thus improving managers’ decision-making and corrective actions, both based on accurate and timely information.

—Superior capacity for the analysis of efficiency trends in the various shops, processes and products.

This situation increases managers’ capability to promote improvements in productivity and more accurate estimates for future projects. In short, the system helps to foresee situations and problems, increasing the competitiveness of the shipyards.

A number of improvements and extensions are planned for the described production control system:

• Improved connection to planning systems.
• Full development and use of the product concept. Integration of materials in the control system.
• Development of an object repository for connection with CAD systems and production engineering.
• Development of a graphical deviation analysis module.
• Development of a module for the simulation of production decisions.

The production control system is meant to be a useful element in the planned computer integrated manufacturing system envisioned as necessary to keep yards competitive in the global shipbuilding market.

Acknowledgments

The authors would like to acknowledge Mr. John J. Dougherty for his work and continual advice during the time of the system basic development.

During the preliminary stages of this project, contact was established with other advanced shipyards, especially Saint John Shipbuilding Ltd., which gave us important ideas and suggestions on the way to translate the very sophisticated cost, schedule and control systems to this production control system, more adequate for a commercial shipbuilding program.

Last, but not least, the authors thank the great efforts of the cooperating production teams in the test shipyard, who gladly passed along their experience and who suffered all our mistakes.

Bibliography


Discussion

Frank H. Rack, Managing Change, Inc., Dickinson, Texas

The authors have presented a very detailed description of their implementation of the product work breakdown structure (PWBS) system and the development of a new production control (PC) system that uses earned value techniques. “This project is included in a larger Production and Competitiveness Improvement Project, . . . (or Integrated Technology Improvement Plan) performed during the past five years, using some ideas from the National Shipbuilding Research Program (NSRP) and documentation.”

It is suggested that some of the basic assumptions upon which the described program concepts are based should be reviewed in light of more recent NSRP Ship Production Symposium papers which essentially present alternatives and/or comments on the bottom line effectiveness of PWBS and PC systems that are being implemented.

“The dilemma . . . is that U.S. shipyards which do utilize product-oriented methodology still fall behind schedule, still overrun budgets, and still are not internationally competitive” (Rogness 1991). (Additional references follow this discussion.) Several major causes that continue to contribute to shipyard low productivity and competitiveness were described by Frankel in 1991, and at this 1995 Symposium. This discusser in 1991 and at this 1995 Symposium itemized major conflicts in approaches (paradigms) in several major areas and used the Theory of Constraints (TOC) Evaporating Cloud (EC) technique for challenging assumptions that lead to the identification of the alternative courses of action. Figures 4 and 5 and Table III cover the Economical Order Quantity (Economical Batch Size) concept, Fig. 6 and Table IV cover shipbuilding scheduling, Fig. 7 and Table VI cover improvement programs, and Fig. 8 and Table VII cover the important measurement subject (Rack 1995).

The fundamental conflict is identified by Goldratt and Fox (1986) in their description of “What Rules Drive Your Business?” The nine Conventional Rules and “Motto: The only way to reach a global optimum is by insuring local optima,” or the nine Global Rules and “Motto: The sum of the local optima is not equal to the global optimum.” The systems being implemented appear to be based on traditional (“Conventional Rules”) which concentrate on improving the “links” (local areas) in the chain and not on the identification, exploiting and elevating (breaking) the weakest link (core problem).

Additional references


Louis D. Chirillo, Bellevue, Washington

The authors’ paper justifies a full day of this Symposium’s program for its presentation and discussion. Señors de la Fuente and Manzanares have produced a clear description
of the multidimensional information matrix that must be commanded for the world-class competition. By command, I do not mean just the processing of information. I mean grouping the same information in layers of definitization that simultaneously match a process work breakdown structure, an organizational work breakdown structure, and a product work breakdown structure. I also mean mechanisms for linking the various structures in a way that allows any management functionary at any management level to extract business information pertinent to the scope of assigned responsibility. In my less sophisticated style, I often express the need for information, work, and people to be organized the same way per a product work breakdown structure.

There is another aspect that is important even with the reduced rate of building, converting, and overhauling naval ships, that is, the authors' description of how cost schedule control is incorporated. The latter approach, proven during construction of Canadian frigates, is now being applied by Astilleros Españoles, S.A. for construction of commercial ships. I have previously reported in a discussion that some world-class shipbuilders developed cost schedule control for building merchant ships that complies with U.S. Department of Defense Instruction 7000.2 without them ever being prompted by a government instruction. Instead, they were motivated by good business sense. They could better see the need for and benefit from cost schedule control because of their use of a product work breakdown structure. To them, budgeted cost of work scheduled (BCWS) is like management saying to a work team at a particular stage on a specific work flow, "If you process this amount of material in the next report period, we will give you so many credits. If you process less, you will get less accordingly. We will call what you earn budgeted cost of work performed (BCWP)" (Chirillo 1993).

Regarding the authors' identification of difficulties, the need to persuade foremen and workers of the importance of not purposely mischarging spent hours attracted my special attention. After rationalized work flows are normalized in a statistical sense, work hours required to process materials will be sufficiently related to the materials for the purpose of simplifying cost reporting. For progress purposes all that needs to be known per work flow is the amount of material processed and the number of workers assigned to that flow per report period. All other data can be obtained by proration and opportunities for mischarging are reduced, provided there is also control by just-in-time delivery of material pallets.

Regardless, the problem of mischarging, which is prevalent in traditionally operated shipyards worldwide, has to be addressed with high priority. A production control system based on earned value concepts, which I think is prerequisite for world-class competition, entails a profound change in corporate culture. The same change, really a revolution, is being managed by the Boeing Company wherein the advocates of change found that, "A big obstacle is entrenched autocratic culture, where information is something old-line managers guard jealously." In this connection, we should all consider one of the main advantages noted by the authors, "Swift and ad-hoc information, thus improving managers' decision-making..." since their system is designed to extract information at every summary level, surely the authors also mean that business information commensurate with workers' responsibilities will be provided so that workers may also participate in decision-making (The Seattle Times 1991).

Congratulations and many thanks to the authors for a paper that I nominate for the best of the symposium. Also, congratulations to their mentor, Señor John J. Dougherty, who had the logic and some pertinent software in place about 20 years ago. Because of that, he was the first in North America to appreciate the profound nature of the product work breakdown structure that was published by the National Shipbuilding Research Program in November 1980.

Additional references


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The authors clearly show the essential use of PWBS as part of an integrated production control system. However, if this is all it is used for, it is an unnecessary and unfortunate limitation.

A PWBS can and should be the basis on which the engineering is prepared, the material is ordered and controlled, the ship is built and total shipyard performance evaluated.

So often PWBSs are developed by single departments and not used as a total integrator. In some shipyards, the financial department develops the PWBS to suit its cost recording and reporting needs. Usually such a PWBS is not of any use to any other department. In other shipyards the production department develops the PWBS and although probably more useful to other departments such as engineering, it is not used by them for a number of reasons, such as not being available until most of the engineering is completed. This, unfortunately, requires other production functions, such as production engineering, to assign the PWBS to the engineering and material definition, which will have been identified in a non-PWBS way. This is an obvious time-delaying action and duplication of effort. It is therefore encouraging that the authors plan to connect their CAD system and P.E. directly to the production control system.

Recognizing that the authors had to stay within a page limit, I would like to ask them to clarify some of their PWBS approach and terminology. While the general approach can be seen from Fig. 1, it is not clear to the discussers as to the meaning of some of the labels, such as "RR," "FM," etc. Could the authors please give a brief description of the interim product classes and the meaning of the labels?

In closing I offer my thanks to the authors for their presentation and my congratulations on their efforts to improve shipbuilding by applying a new paradigm.