# A NEW APPROACH TO SCHEDULING AND CONTROL OF JOB-SHOP PRODUCTION

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*Programarea şi conducerea producţiei continuă să fie o problemă deosebit de actuală, atât pentru cercetători, cât şi pentru managerii din industrie. Soluţiile cunoscute în acest domeniu sunt de o mare diversitate şi, în multe dintre cazuri, contradictorii.*

*În lucrarea de faţă se propune o nouă abordare subordonată conceptului de proiect de producţie.*

*In cadrul acestei abordări, punctul de plecare îl constituie resursele de producţie, iar finalitatea constă într-un indicator de referinţă al urmăririi producţiei, denumit Sarcina cumulată planificată, exprimată în costuri (BCWS).*

*Production scheduling and control continues to be an important and actual challenge for the researchers and practitioners in the production management field. The reported solutions in this management area are extremely diverse and, in many cases, completely opposite.*

*This paper presents a new approach to manufacturing scheduling and control problem that relies on the concept of production project.*

*The main concern of this approach is the usage of production resources, which is controlled by means of a reference indicator named the Budgeted Cost of Work Scheduled (BCWS).*

**Keywords**: individual resource load report, project's resource pool load report, cumulative load table, cumulative cost charts.

## Introduction

It is well known [1, 2, 3, 4] that operational management of production is carried out by performing a set of functional activities for production planning, scheduling, and control.

Production planning is responsible for the long and medium term regulation of manufacturing activities in the firm. The main operational feature of production planning is the balance of capacity required and capacity available of manufacturing resources.

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Production scheduling sets the short term rate of manufacturing activities. Its operational output consists in short term scheduled dates to perform production activities on resources.

Planning and scheduling are strongly interconnected, especially in a job-shop production environment. In this case, the decisions taken at the planning level affect the scheduling solutions, which, in turn, may influence future planning.

Because the availability of resources over time must be taken into account at the planning level, production scheduling may be considered as a planning stage. This point of view is common in the literature. For example, Melnic [3] quotes from Stobbe [5] that is not possible to make delimitations between production planning and production scheduling.

Production control has two essential tasks [4, 6]: to release work orders to the shop according to the scheduled data and to coordinate the execution of orders so as to be completed on time. The progress of manufacturing orders is tracked and adjusted against the existing production schedule. If the orders are behind schedule, this function may trigger a necessary rescheduling of the manufacturing activities.

This brief presentation of the operational management field is helpful to put in sight the great complexity of managerial tasks. Moreover, production scheduling and control become more important knowing that in a job-shop environment orders may spend a lot of time in queues. The references cited by Melnic [3] indicate an 80 % average queue time of manufacturing orders in the production shops.

There are many approaches to scheduling and control of job-shop production [1, 2, 3, 4, 6], based on contradictory principles and diverse terminologies.

This paper presents a new approach to scheduling and control in the job-shop production environment that makes use of some concepts and methods specific to project management. A definition of production project is as follows [7]: "the production project comprises a set of actions and tasks dedicated to the preparation, the release, and the coordination of production".

Besides the fundamental project management concepts [7, 8, 9, 10], some new notions were developed and used to support the proposed approach.

## 1. Load reports of individual resources and for project's resource pool

The conceptual basis and the logical formalization elements of production scheduling and control must be simple and clearly defined. These elements must assure a simple and precise description of materials flows, resources allocations, and production progress through the shop.

The fundamental formalization element is the logical network of production project [4, 7] or the technological network of materials flow [3]. The latter model is an extension of the former that offers additional information regarding "the units of processing flow and of waiting flow in the shop".

The network-planning model of the project can be firstly used to perform the PERT-time calculations of the project, including the determination of: earliest start and finish times for activities; latest start and finish times of activities; slacks of activities and project's critical path. Thorough and comprehensive reviews of the theoretical and practical aspects of PERT-time calculations are presented by Neagu [4, 7].

PERT-time data and resource-specific information of the network model can be used afterwards to construct the load reports of individual resources and for the project's resource pool. In a resource-constrained scheduling situation, PERT-load models or activities sequencing models [4, 7] can also be used in order to obtain the load reports.

These reports illustrate the usage of production resources through time for the execution of project's tasks according to the logic of network model.

The load reports of six individual resources that are used to process three lots of different parts released in the shop are presented in Fig. 1.

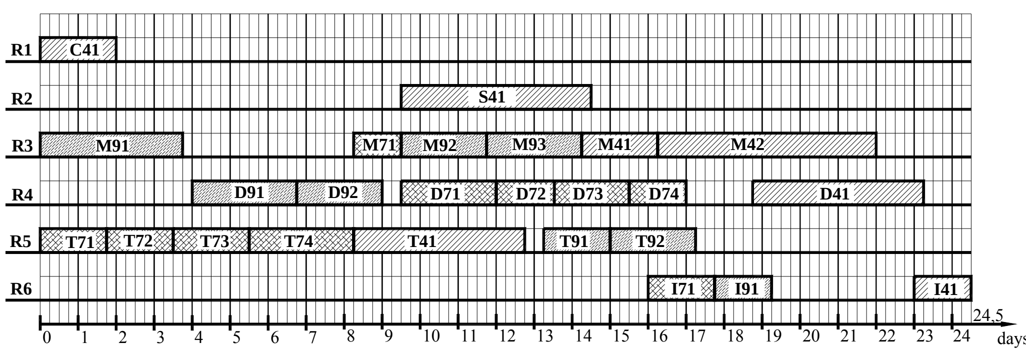


Fig. 1. Load reports of individual production resources

In Fig. 1, production resources denoted R1, ..., R6 represent workstations for different technological operations, as follows: R1, cutting machine; R2 – shaping machine; R3 – milling machine; R4 – drilling machine; R5 – turning machine; R6 – inspection bench.

Technological operations for the lots of parts are indicated in Fig. 1 by a coding scheme comprising a leading capital letter and two trailing digits: the letter stands for the process (and resource) type to be used for performing the operations; first digit represents the part's code in the product structure diagram [4, 7] or in the bill of material (BOM) file; second digit denotes the rank of processing operation in the manufacturing routing of the part on each resource. For example, M93 is the third milling operation for the part number 9 of BOM.

The load reports in Fig. 1 show daily assignments of the project resources during a complete production cycle of the three parts (T), where T is 24,5 working days long. A 8-hours working time per day was considered for the resources in Fig. 1.

By cumulating on a daily basis the loads on all project resources, the profile in Fig. 2 comes up. This is the load report for the entire project resource pool.

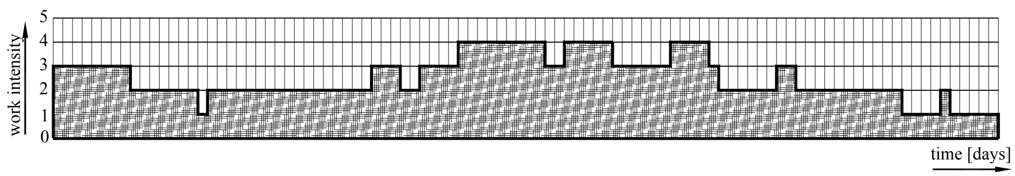


Fig. 2. Load report of project's resource pool

Total load on the project's resource pool during the manufacturing cycle time (T) is indicated by the shaded area in Fig. 2. Its value can be easily obtained by integrating work intensity function with respect to time. For the example in Fig. 2, the accumulated total load on project's resource pool (Lc) over the manufacturing cycle equals 63 working days on resource (63 dr). This result can also be obtained from the calculations in the cumulative load table (see Table 1).

*Table 1*

**Cumulative load [days on resource]**

| Time periods [days] | Resource load for R1 [dr] | | Resource load for R2 [dr] | | Resource load for R3 [dr] | | Resource load for R4 [dr] | | Resource load for R5 [dr] | | Resource load for R6 [dr] | | Cumulative load for project [dr] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | current | total | current | total | current | total | current | total | current | total | current | total | |
| 0.0 - 2.0 | 2 | 2 | 0 | 0 | 2 | 2 | 0 | 0 | 2 | 2 | 0 | 0 | 6 |
| 2.0 -3.75 | 0 | 2 | 0 | 0 | 1.75 | 3.75 | 0 | 0 | 1.75 | 3.75 | 0 | 0 | 9.5 |
| 3.75 - 4.0 | 0 | 2 | 0 | 0 | 0 | 3.75 | 0 | 0 | 0.25 | 4 | 0 | 0 | 9.75 |
| 4.0 - 8.25 | 0 | 2 | 0 | 0 | 0 | 3.75 | 4.25 | 4.25 | 4.25 | 8.25 | 0 | 0 | 18.25 |
| 8.25 - 9.0 | 0 | 2 | 0 | 0 | 0.75 | 4.5 | 0.75 | 5 | 0.75 | 9 | 0 | 0 | 20.5 |
| 9.0 - 9.5 | 0 | 2 | 0 | 0 | 0.5 | 5 | 0 | 5 | 0.5 | 9.5 | 0 | 0 | 21.5 |
| 9.5 - 12.75 | 0 | 2 | 3.25 | 3.25 | 3.25 | 8.25 | 3.25 | 8.25 | 3.25 | 12.75 | 0 | 0 | 34.5 |
| 12.75 -13.25 | 0 | 2 | 0.5 | 3.75 | 0.5 | 8.75 | 0.5 | 8.75 | 0 | 12.75 | 0 | 0 | 36 |
| 13.25 - 14.5 | 0 | 2 | 1.25 | 5 | 1.25 | 10 | 1.25 | 10 | 1.25 | 14 | 0 | 0 | 41 |
| 14.5 -16.0 | 0 | 2 | 0 | 5 | 1.5 | 11.5 | 1.5 | 11.5 | 1.5 | 15.5 | 0 | 0 | 45.5 |
| 16.0 - 17.0 | 0 | 2 | 0 | 5 | 1 | 12.5 | 1 | 12.5 | 1 | 16.5 | 1 | 1 | 49.5 |
| 17.0 - 17.25 | 0 | 2 | 0 | 5 | 0.25 | 12.75 | 0 | 12.5 | 0.25 | 16.75 | 0.25 | 1.25 | 50.25 |
| 17.25 -18.75 | 0 | 2 | 0 | 5 | 1.5 | 14.25 | 0 | 12.5 | 0 | 16.75 | 1.5 | 2.75 | 53.25 |
| 18.75 -19.25 | 0 | 2 | 0 | 5 | 0.5 | 14.75 | 0.5 | 13 | 0 | 16.75 | 0.5 | 3.25 | 54.75 |
| 19.25 - 22.0 | 0 | 2 | 0 | 5 | 2.75 | 17.5 | 2.75 | 15.75 | 0 | 16.75 | 0 | 3.25 | 60.25 |
| 22.0 - 23.0 | 0 | 2 | 0 | 5 | 0 | 17.5 | 1 | 16.75 | 0 | 16.75 | 0 | 3.25 | 61.25 |
| 23.0 - 23.25 | 0 | 2 | 0 | 5 | 0 | 17.5 | 0.25 | 17 | 0 | 16.75 | 0.25 | 3.5 | 61.75 |
| 23.25 - 24.5 | 0 | 2 | 0 | 5 | 0 | 17.5 | 0 | 17 | 0 | 16.75 | 1.25 | 4.75 | **63** |

## 2. Cumulative cost charts

By transforming the time-phased cumulative load in Table 1 in related cost for resource work, we obtain a cumulative planned cost (see Table 2) known as the Budgeted Cost of Work Scheduled (BCWS). This is a reference indicator for project control. In Table 3 are indicated the hourly costs for resources work that are used for the calculation of BCWS values. The detailed procedure to compute these costs for the simultaneously-processed parts in a shop is presented by Neagu [4, 7]. In Table 2, a working day on resource (dr) totals 8 hours of resource work (hr).

*Table 2.*

**Budgeted cost of work scheduled [EURO]**

| Time periods [days] | Cumulative work R1 | | | Cumulative work R2 | | | Cumulative work R3 | | | Cumulative work R4 | | | Cumulative work R5 | | | Cumulative work R6 | | | BCWS [€] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | [dr] | [hr] | [€] | [dr] | [hr] | [€] | [dr] | [hr] | [€] | [dr] | [hr] | [€] | [dr] | [hr] | [€] | [dr] | [hr] | [€] | |
| 0.0 - 2.0 | 2 | 16 | 104.16 | 0 | 0 | 0 | 2 | 16 | 165.44 | 0 | 0 | 0 | 2 | 16 | 151.68 | 0 | 0 | 0 | 421.28 |
| 2.0 -3.75 | 2 | 16 | 104.16 | 0 | 0 | 0 | 3.75 | 30 | 310.2 | 0 | 0 | 0 | 3.75 | 30 | 284.4 | 0 | 0 | 0 | 698.76 |
| 3.75 - 4.0 | 2 | 16 | 104.16 | 0 | 0 | 0 | 3.75 | 30 | 310.2 | 0 | 0 | 0 | 4 | 32 | 303.36 | 0 | 0 | 0 | 717.72 |
| 4.0 - 8.25 | 2 | 16 | 104.16 | 0 | 0 | 0 | 3.75 | 30 | 310.2 | 4.25 | 34 | 253.3 | 8.25 | 66 | 625.68 | 0 | 0 | 0 | 1293.34 |
| 8.25 - 9.0 | 2 | 16 | 104.16 | 0 | 0 | 0 | 4.5 | 36 | 372.24 | 5 | 40 | 298 | 9 | 72 | 682.56 | 0 | 0 | 0 | 1456.96 |
| 9.0 - 9.5 | 2 | 16 | 104.16 | 0 | 0 | 0 | 5 | 40 | 413.6 | 5 | 40 | 298 | 9.5 | 76 | 720.48 | 0 | 0 | 0 | 1536.24 |
| 9.5 - 12.75 | 2 | 16 | 104.16 | 3.25 | 26 | 181.7 | 8.25 | 66 | 682.44 | 8.25 | 66 | 491.7 | 12.75 | 102 | 966.96 | 0 | 0 | 0 | 2427 |
| 12.75 -13.25 | 2 | 16 | 104.16 | 3.75 | 30 | 209.7 | 8.75 | 70 | 723.8 | 8.75 | 70 | 521.5 | 12.75 | 102 | 966.96 | 0 | 0 | 0 | 2526.12 |
| 13.25 - 14.5 | 2 | 16 | 104.16 | 5 | 40 | 279.6 | 10 | 80 | 827.2 | 10 | 80 | 596 | 14 | 112 | 1061.76 | 0 | 0 | 0 | 2868.72 |
| 14.5 -16.0 | 2 | 16 | 104.16 | 5 | 40 | 279.6 | 11.5 | 92 | 951.28 | 11.5 | 92 | 685.4 | 15.5 | 124 | 1175.52 | 0 | 0 | 0 | 3195.96 |
| 16.0 - 17.0 | 2 | 16 | 104.16 | 5 | 40 | 279.6 | 12.5 | 100 | 1034 | 12.5 | 100 | 745 | 16.5 | 132 | 1251.36 | 1 | 8 | 75.12 | 3489.24 |
| 17.0 - 17.25 | 2 | 16 | 104.16 | 5 | 40 | 279.6 | 12.75 | 102 | 1054.68 | 12.5 | 100 | 745 | 16.75 | 134 | 1270.32 | 1.25 | 10 | 93.9 | 3547.66 |
| 17.25 -18.75 | 2 | 16 | 104.16 | 5 | 40 | 279.6 | 14.25 | 114 | 1178.76 | 12.5 | 100 | 745 | 16.75 | 134 | 1270.32 | 2.75 | 22 | 206.5 | 3784.42 |
| 18.75 -19.25 | 2 | 16 | 104.16 | 5 | 40 | 279.6 | 14.75 | 118 | 1220.12 | 13 | 104 | 774.8 | 16.75 | 134 | 1270.32 | 3.25 | 26 | 244.1 | 3893.14 |
| 19.25 - 22.0 | 2 | 16 | 104.16 | 5 | 40 | 279.6 | 17.5 | 140 | 1447.6 | 15.75 | 126 | 938.7 | 16.75 | 134 | 1270.32 | 3.25 | 26 | 244.1 | 4284.52 |
| 22.0 - 23.0 | 2 | 16 | 104.16 | 5 | 40 | 279.6 | 17.5 | 140 | 1447.6 | 16.75 | 134 | 998.3 | 16.75 | 134 | 1270.32 | 3.25 | 26 | 244.1 | 4344.12 |
| 23.0 - 23.25 | 2 | 16 | 104.16 | 5 | 40 | 279.6 | 17.5 | 140 | 1447.6 | 17 | 136 | 1013.2 | 16.75 | 134 | 1270.32 | 3.5 | 28 | 262.9 | 4377.8 |
| 23.25 - 24.5 | 2 | 16 | 104.16 | 5 | 40 | 279.6 | 17.5 | 140 | 1447.6 | 17 | 136 | 1013.2 | 16.75 | 134 | 1270.32 | 4.75 | 38 | 356.8 | 4471.7 |

*Table 3.*

**Hourly costs for the work of production resources [EURO/hour]**

| Production resources | | Total cost components | | | | Hourly cost |
|---|---|---|---|---|---|---|
| Code | Technological type | C1, current costs | C2, fixed costs | C3, opportunity costs of the capital investment in the work in process (WIP) | C4, depreciation costs of resources | $C_T$, total cost |
| R1 | Cutting machine | 2.7 | 0.15 | 0.08 | 3.58 | 6.51 |
| R2 | Shaping machine | 3.1 | 0.18 | 0.09 | 3.62 | 6.99 |
| R3 | Milling machine | 4.8 | 0.22 | 1.1 | 4.22 | 10.34 |
| R4 | Drilling machine | 3.62 | 0.16 | 0.09 | 3.58 | 7.45 |
| R5 | Turning machine | 4.52 | 0.24 | 1.12 | 3.6 | 9.48 |
| R6 | Inspection bench | 5.2 | 0.21 | 1.1 | 2.88 | 9.39 |

By plotting BCWS values in Table 2 over time, we obtain the curve shown in Fig. 3. This is the BCWS chart for the example project.

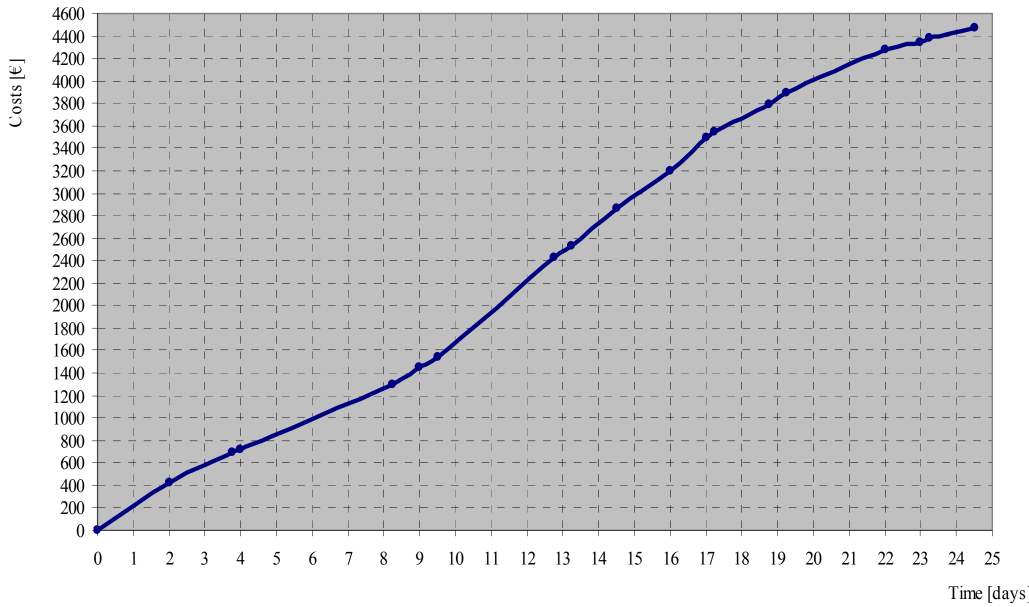


Fig. 3. Budgeted cost of work scheduled (BCWS)

When used for production project control, BCWS shows the timing and the amount of planned expenditures for the implementation of the project. So, it gives the manager an answer to the following question: What is the cost of the planned (expected) progress of the project?

However, actual progress of the project may differ from the planned data. In this case, the performance of the project implementation can be evaluated with the help of a second indicator, which is the Budgeted Cost of Work Performed (BCWP). BCWP is the expected cost of the actual work done so far. As a result, it answers the following managerial question: What is the expected cost of the actual progress of the project? If this cost is higher than planned by a moment, more work has been done till then and the project is before schedule (in advance). On the contrary, if this cost is less than planned, the project is behind schedule (delayed). So, the advance or the delay of a project can be assessed by comparing BCWP and BCWS. BCWP data can easily be obtained from BCWS in Table 2, by summing up the costs only for the work performed so far.

Sometimes, actual costs are different from projected costs. For this reason, a third performance indicator of the project must be taken into account. This is the Actual Cost of Work Performed (ACWP) that indicates the money actually spent to accomplish the work done so far. So, this indicator answers the question: What is the actual cost of the actual progress of the project? If the actual cost is greater than projected for the work done, the project is over budget. Contrarily, the project is under (within) budget. So, project implementation costs can actually be controlled by comparing ACWP and BCWP.

BCWP and ACWP curves can be charted independently, as shown for BCWS (see Fig. 3). However, to facilitate project control activities, the three cumulative cost curves are usually plotted on the same chart, as indicated in Fig. 4.

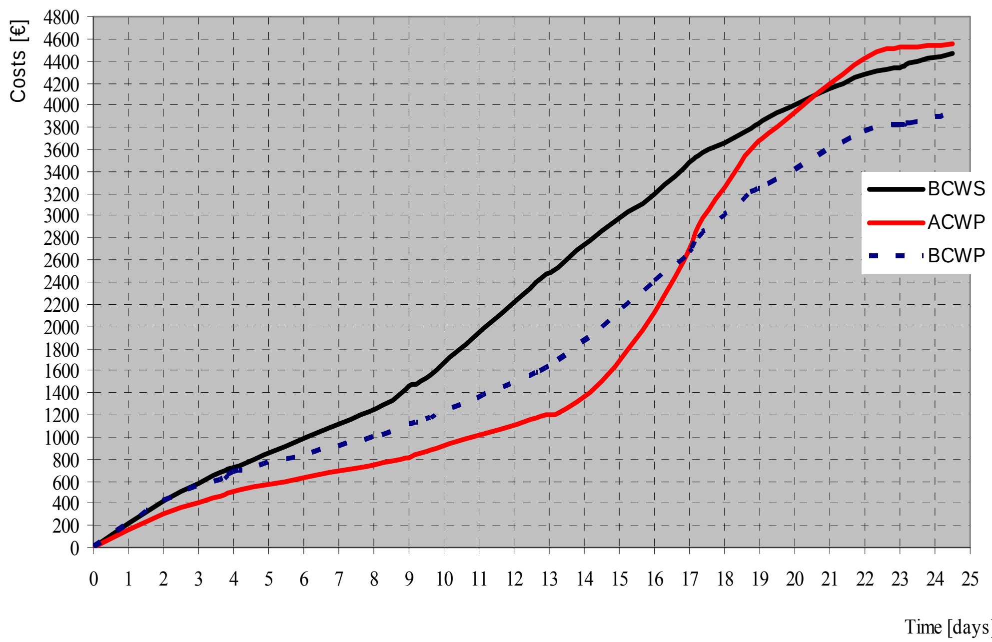


Fig. 4. Combined chart of BCWS, BCWP, and ACWP

The example chart in Fig. 4 tracks the recorded values of BCWS, BCWP, and ACWP indicators, from the release of the production orders in the shop to the planned finish time of the manufacturing cycle for the three parts (T).

Since BCWP line is below BCWS line, the project is progressing slower than expected. So, it is behind schedule all the time.

Because ACWP curve is under BCWP curve for the first 17 working days of the manufacturing cycle, the expenditures for the project implementation are lower than projected for this period. However, the production project is delayed.

Starting with the beginning of the 18$^{th}$ working day, actual cost of work done exceeds budgeted cost (ACWP > BCWP), in spite of the fact that the project is still delayed.

## Conclusions

This paper describes a new approach to production scheduling and control in the job-shop environment. The approach is founded on the concept of production project and on project management theory. These basics were used to build up the logical formalization of production scheduling and control problem. This formalization and some new-developed theoretical elements supporting the approach are intended to assure a precise tracking of resource usage through time, in order to reduce cost and schedule variances at the implementation of production projects.

The following new elements were devised to support the proposed scheduling and control approach: the load reports of individual production resources; the load report of the entire project resource pool; the cumulative planned cost chart (BCWS chart).

The load reports of individual resources depict the planned usage of resources through time for the execution of project's tasks according to the logic of network model. An overall image of the planned usage of resources for the entire project is created by the load report of project's resource pool.

BCWS chart that comes up by costing out the planned usage of resources has a central role in project control. BCWS, together with BCWP and ACWP permit to evaluate the performance of project implementation in terms of time and money.

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