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Designing a Control Mechanism for Production Planning Problems by Means of Earned Value Analysis

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Abstract: In this study, a Production Planning Problem (PPP) known as Multi Product Multi Period (MPMP) where the operation sequence is known is described. It is also shown how a mechanism for controlling MPMP can be created by applying Earned Value Analysis (EVA). This mechanism which has not been reported in the literature enables the control of production status and consequently forecasting of the required time and cost for completely fulfilling customer's demand during a manufacturing process. Thus, it is shown that PPP can be integrated with powerful project control tools such as EVA.

Key words: Production planning, project control, earned value analysis, control mechanism, budget at completion

INTRODUCTION

As planning is an activity that occurs prior to control in manufacturing environments, the majority of research papers found in the literature discuss production planning rather than its control mechanism. However, it is obvious that planning without control is not effective. In this respect, it is important to integrate both planning and control activities into a unique program. This implies that production control must be carried out based on an earlier plan. Otherwise, the performance of the production system e.g., on-time and on-budget delivery to customer cannot be measured accurately. Actual records from a production planning horizon can be also used for planning the resulting production.

Analytical models, e.g., Linear Programming (LP) techniques, may generate infeasible solutions for practical problems due to their ignorance of some facts during modeling. The literature indicates that hybrid analytical-simulation analysis can be efficiently performed (Byrne and Bakir, 1999). Therefore, optimization techniques such as LP models are unable to consider some operational criteria in a machine-shop such as machine order visit as proposed and modeled by Byrne and Bakir (1999), Kim and Kim (2001) and finally Byrne and Hossain (2005). In the approaches advocated by the above authors, the initial production plans have been generated by applying LP formulations and then the results found by LP are taken as input to a simulation model in order to adjust capacity for producing each of the products. Simulation analysis is stopped whenever the total output is feasible in accordance with capacity constraints and operational criteria available in the shop. On the other hand, some research papers were found to be focused mainly on shop floor control concepts in order to control manufacturing processes and production environments. Monch (2007) described benchmarking efforts for production control in complex manufacturing environments where large numbers of products, sequence dependent set up times, mixtures of different process types and internal-external disturbances were included. Monch suggested software for production control and discussed limitations of proposed software in different application areas. Monostori *et al*. (2007) summarized the main challenges and issues associated with customized mass production control. They applied both traditional discrete event simulation and agent based approaches and tested the effectiveness of their proposed approach using experimental data from industry.

Lia and Liu (2006) proposed a production system in two stages (including upstream and downstream) where significant setup times at the upstream levels were considered. A threshold production control system was also employed in order to minimize total work in process mainstreaming at the required downstream level. Finally a Markov model was constructed and numerical optimization performed using a simple algorithm.

Csajia *et al*. (2006) presented an adaptive scheduling system which performs in a market based production control system thorough a triple level learning mechanism.

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Numerical function approximator, reinforcement learning system and simulated annealing algorithm were thus considered in lower, medium and higher levels respectively. They also examined time and space complexity of the solution using experimental investigations.

Al-Tahata and Mukattash (2006) designed production control schemes for Kanban based Just-in-Time (JIT) environments. For this reason, the Kanban system was formulated as a queuing model and a new approach was discussed for analyzing it. Also numerical examples for determining parameters of system were provided.

Dassisti and Galantucci (2005) proposed a commercial use of object oriented discrete event simulator called pseudo fuzzy discrete event simulation where the fuzzy operator was used as a simulator embedded with stochastic function in order to facilitate an online production control. Their approach was evaluated through an industrial benchmark.

Gharbi and Kenné (2005) addressed a production and maintenance control problem where multiple-machine manufacturing systems were considered. For both identical and non identical manufacturing systems a two level hierarchical control model was developed. The results obtained extended the previously conducted investigations to address the non identical types that had not been considered accordingly. Sensitivity analysis for robustness and preventive maintenance were thus focused on large scaled manufacturing systems.

Kenne and Gharbi (2004) focused on manufacturing systems where machine maintenance and constant demand rate were assumed in order to minimize discounted inventory holding costs and backlogging costs over the planning horizon. It is pointed out that production and machine repair rates had to be considered as decision variables. Finally they showed that hedging point policy is optimal.

Barker (2001) focused on implementation of time based value adding strategy and pull-type block control in an electrical manufacturing company and took numerous corrective actions in order to improve value adding processes.

Kogan and Lou (2002) analyzed a manufacturing environment with tandem machines where the system periodically stopped for maintenance. The objective was to minimize total inventory and backlogging expenses which was demonstrated using a numerical example and it was found that in order to present optimal production policy only restricting machines needed to be considered.

EARNED VALUE MANAGEMENT SYSTEM (EVMS)

Earned value method: Earned Value (EV) is a method for managing projects in such a way to incorporate scope and integrate it with both project time and cost points of view. Thus, planned value (PV)-sometimes called as the Budgeted Cost for Work Scheduled (BCWS)-can be calculated based on distribution of activity budget on its own duration. Thus, planned value represents total expenditures to be spent versus time. Summation of planned value at the end of project is called Budget at Completion (BAC), which is usually considered for project performance measurement. It is obvious that BAC is usually less than contract price. That is why, some of cost components such as overhead and some other expenditure cannot be explicitly distributed over time. On the other hand, actual cost (AC)-also called Actual Costs of Work Performed (ACWP)-of work performed must be totally calculated up to project data date. The amount of EV-also referred to as the Budgeted Cost of Work Performed (BCWP)-can be measured by progress achieved for each activity. It is thus calculated by multiplying the progress of each activity on its assigned budget.

PV, AC and EV, at each data date (or report date) can be compared and the corresponding cost performance index (CPI) and schedule performance index (SPI) can be easily calculated as follows (Project Management Body of Knowledge, 2004):

$$CPI = \frac{EV}{AC} \tag{1}$$

$$SPI = \frac{EV}{PV} \tag{2}$$

Generic model of EV method is presented in Fig. 1.

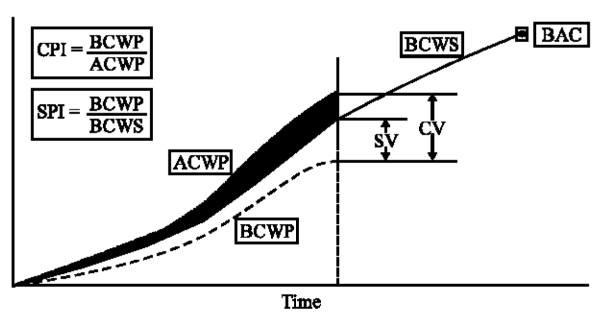

Fig. 1: Generic model of EV method

EV analysis: literature survey: The EV method is extended mainly into two areas. The first category of research is related to working on EV developments or extension in EV metrics or principle. The second type of research area attempts to address applications of EV management system in both organizations and projects. Therefore, the focus is on how to implement EV efficiently. However, some of research articles described both points of view.

As an important research work on EVA and forecasting features, Vandevoorde and Vanhoucke (2006) not only concentrated on traditional EV metrics, but also developed earned schedule performance indicators namely SV(t) and SPI(t). Their proposed approach was also able to yield forecast of total project duration. Their developed formula was compared with three available methods in the literature based on testing three real life projects in several situations. Although they claimed superiority for their proposed approach, they speculated that depending on every situation, e.g., project manager's knowledge and the formation of project management team, other methods may also be useful.

Vitner *et al.* (2006) applied a data envelopment analysis (DEA) for performance evaluation in a multi project environment where each project was defined uniquely. They integrated EV management system (EVMS) with multi denominational control system (MPCS). They also provided a new approach in order to reduce the number of inputs and outputs in their developed approach to achieve better results in multi project environments. However, they claimed that it was for the first time that DEA was being applied in project environment as it had been previously only used in organizations e.g., hospital, banking etc.

Moslehi *et al.* (2004) presented an integrated web based time and cost control system for construction projects which mapped Work Breakdown Structure (WBS) into an object oriented model to enable generating EV reports at control objects and resource levels. Moreover, in order to analyze project variance, a set of resource performance indicators was used. Their system also assisted to share data within the World Wide Web.

Stratton (2007) discussed applying earned schedule analysis in order to estimate completion date. Firstly, he presented commonly used EV technique including schedule performance index (SPI) and then discussed that SPI (t) can be estimated based on earned schedule divided on actual time where earned schedule can be calculated based on mapping EV amount on time (horizontal) axis.

As it is evident from the above literature survey, PPP and project management areas are extensively discussed. However no related research could be found where both earned value analysis and production planning concept were used simultaneously in order to control the production status in manufacturing environment. As only related work, PPPs were solved by applying project scheduling techniques by Markus *et al.* (2003). Moreover, they solved common PPPs by project scheduling approach and further they discussed about its application in material and capacity requirements planning problems.

To the best of our knowledge, there is neither any closely related research that proposes a project management technique for production control especially during manufacturing processes. It is also worth noting that regarding multi product-multi period PPPs no specific control mechanism has been published in the literature.

APPLYING EV MANAGEMENT SYSTEMS AS CONTROL MECHANISM IN MANUFACTURING ENVIRONMENTS

Problem statement: The MPMP problem under capacity constraint and machine order visit was initially proposed by Byrne and Bakir (1999) and was followed by Kim and Kim (2001) and Byrne and Hossain (2005), accordingly. The problem consists of multiple products that are to be delivered at multiple periods. Customer demand at each period for each product is assumed to be known and deterministic. There are several machine centers considered whose processing times and machine order visit (sequence to be met) for each product are individually pre-specified. Moreover, the cost coefficient for each product at each period in terms of units of production, inventory holding costs and shortage costs are known. The problem in this paper is also considered under both capacity constraints in machine centers and material balancing.

The objective is to control production rates at each period for each product in order to provide on time-on budget delivery performance for the customer. In this regard, both completion time and cost (budget) must be taken into consideration simultaneously. The approach used in this paper incorporates production control during the implementation of production phase and can therefore have at least the following advantages:

- Identify the production status by comparing planned and actual production amount and provide report for each time as required
- Measure progress achieved and compare with planned progress
- Control production status during manufacturing processes from both time and cost points of view

- Present a simultaneous schedule and cost performance index based on achieved results
- Recognize the gap generated and determine the important results incorporating quick decision making for the managers
- Provide a forecast for both time and cost aspects and raise alarm in the case of over budget/over schedule before finishing the production process

Proposed approach: The approach used in this study is initiated using a hybrid of analytical modeling and simulation analysis applied for MPMP problems as proposed by Byrne and Bakir (1999). That is why the solution is completely feasible resulting from adjusting overloaded capacity. Since the problem must be controlled, it certainly has to be converted to a project management network e.g., activity on node (AON) and consequently a Gantt chart which will yield a detailed time schedule based on results published by Byrne and Bakir (1999) or work presented by Byrne and Hossain (2005).

Thus, the resulting time schedule can be expressed under EV analysis incorporating a simultaneous cost/time control mechanism. At this stage the control period (i.e., how often control actions have to be performed) and the control level (e.g., activity) must be clarified. It must be pointed that in this paper, activity level is consider to be controlled periodically. Thus, each process that must be achieved on a machine for producing a specific product at each period is considered as an activity to be controlled. Cost of each activity must be calculated considering all relevant items and distributed on its own activity accordingly. The cumulative amount called budget at completion (BAC) has to be maintained. BAC will be also used for EV calculation by multiplying BAC by the percentage of progress resulting from progress in production. Finally by comparing, actual costs-associated with activity-, PV and EV, the corresponding indexes can be found to provide a forecasting based on current achieved performance. Thus, this process must be repeated for each control period and at the end of each one, corrective actions in case of bad EV metrics have to be investigated. The stopping condition will occur when the last control period (I) appears. It is obvious that it can be extended until delivery to the customer has been made. The corrective actions may include revision of production plan, injection of new budget or even time/cost trade off in case of being over completion time or customer due date. Finally all related data have to be gathered for subsequent projects. Clearly, a well organized database management system would be helpful in controlling actions. The proposed approach can be found in detail as shown in Fig. 2.

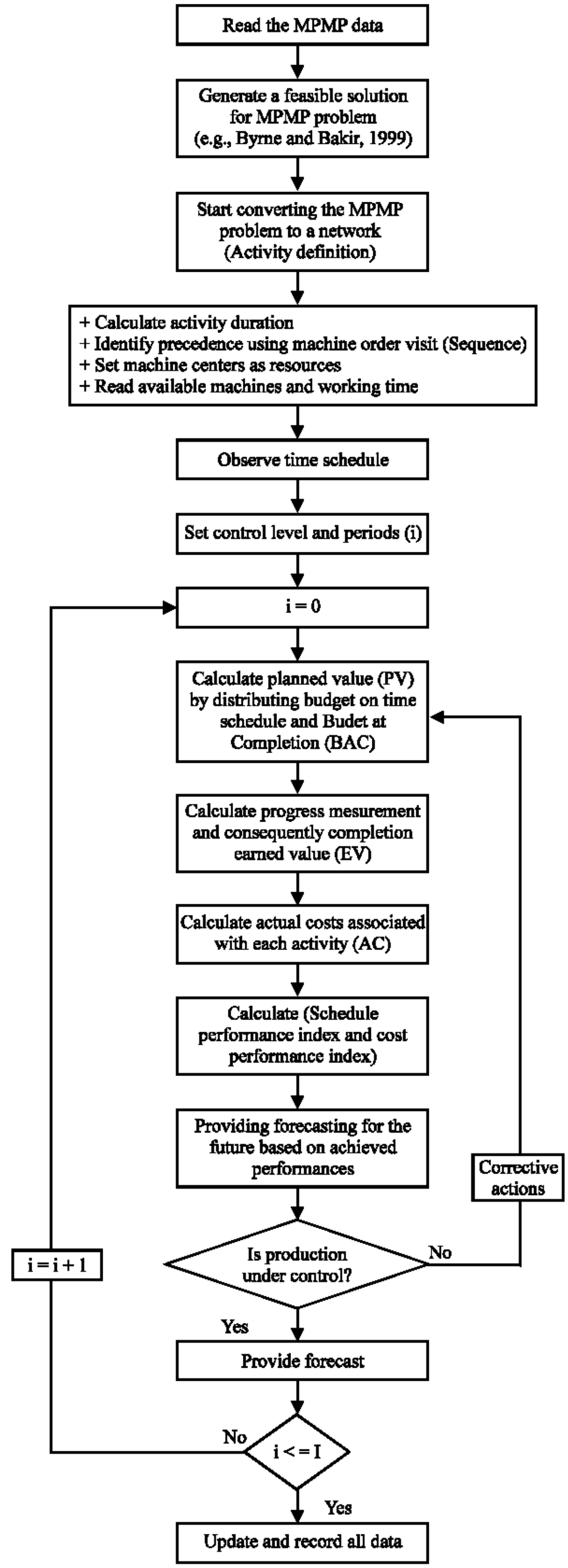

Fig. 2: Control framework for MPMP problems

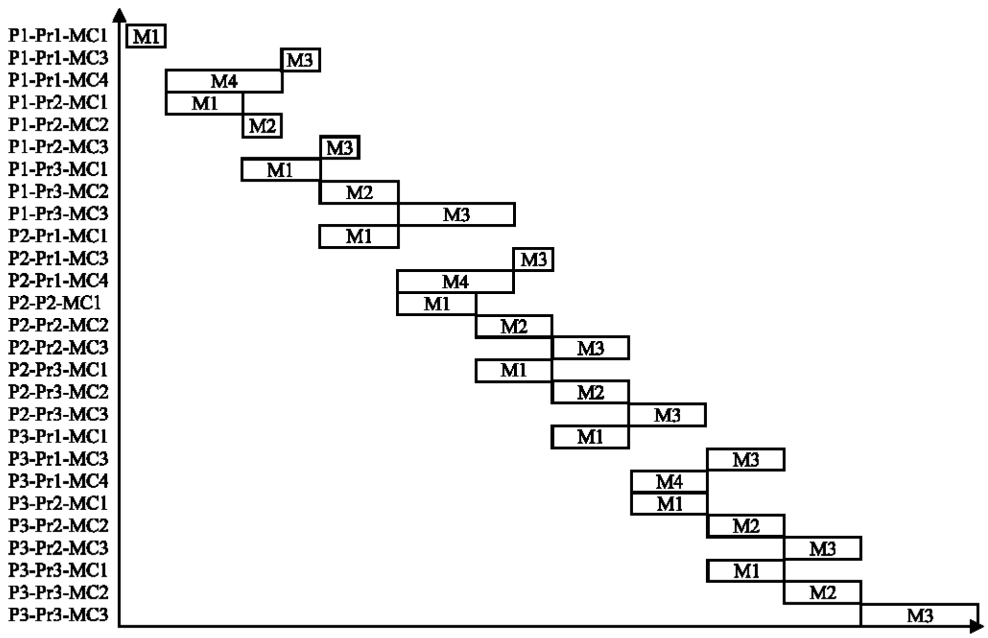

Fig. 3: Production time schedule

Table 1: Cost components

Periods products	Unit production cost 1	2	3	Inventory holding cost 1	2	3	Shortage cost 1	2	3
1	100	100	100	25	25	100	400	400	400
2	150	150	150	30	30	150	450	450	450
3	125	125	125	35	35	200	500	500	500

Table 2: Customer demand

Products	Periods 1	2	3
1	150	125	160
2	100	150	150
3	125	165	125

Table 3: Processing times

Products	Machine center MC1	MC2	MC3	MC4
1	5	-	4	10
2	7	7	5	-
3	7	6	10	-

Table 4: Machine visit order

Products	Machine visit order		
1	MC1	MC4	MC3
2	MC1	MC2	MC3
3	MC1	MC2	MC3

CASE STUDY

The example presented in this paper was initially proposed by Byrne and Bakir (1999) and also Byrne and Hossain (2005). The case consists of a three period, three products PPP to be proceeded through four machine centers, each including one machine and one input buffer. The capacity constraint for each machine is equal to 2400 min per week. Cost components and coefficient for each product, at each period are given in Table 1. Also customer demand, processing times and process routines are given in Table 2-4.

Production time schedule: Based on a feasible production planning approach, the production rate of each product, at each period on corresponding machine center is considered as an activity. Then based of flowchart presented in Fig. 2, after definition of precedence and resource assignment, the production time schedule can be observed as given in Fig. 3.

Planned value: Firstly, planned value of each task including production costs, shortage and lost sale must be calculated. Then the planned value of each activity must be distributed on its own duration. It is thus expected to achieve planned value of each production planning period (e.g., each day) by calculating cumulative amount of activities to be done on a specific date. Method of estimation usually can be considered using normal distribution function. That is why it is common that at the start of project, progress rate of an activity is low and then it will increase up until the middle of its own duration accordingly and then it will decrease until finishing the activity. It is thus expected to apply a normal distribution curve. However, it is possible to try other types of probability distribution functions e.g., log normal, exponential, etc. It is obvious that budget at completion can also be achieved using cumulative amount of planned value of each day.

EV: As a simple calculation method, EV can be calculated based on progress achieved in shop floor multiplied by planned value. Progress (P) achieved for each activity can be calculated based on the following formula:

$$P = \frac{\sum_{i=1}^{n} TAP}{\sum_{i=1}^{n} TPP} \quad (3)$$

Where:

TAP : Total actual production rate
TPP : Total planned production rate
n : Number of activities associated with progress calculation or activities involved

Indeed, in order to calculate progress percentage, total produced products must be divided by total planned production based on time schedule. The progress can be easily calculated for each production planning period e.g., day, week etc.

Actual costs: The actual costs of work performed can be determined for each activity and therefore the total expenditures at the end of production planning period can be thus calculated. It is clear that only the expenditure that had been used in planned value calculations can be further used during actual costs calculations. Hereby, the expenditures must be allocated based on cost codes assigned at the start of project to its own category.

EV measurement: As it is clear in Fig. 4, planned value, EV and actual costs have been drawn versus time. Total amount of EV is less than total actual costs and total actual costs is less than planned value. This means that the manufacturing process is both over schedule and budget. Thus, additional budget and time are required for finishing pre-determined production amounts to be delivered to the customer. The results have been prepared based on current date which is the 10th day from production start time. The values 0.5 and 0.7 have been achieved for SPI and CPI respectively. These are strong indices that on time on budget delivery to the customer cannot occur since CPI and SPI are less than 1. Hereby, it is necessary to take some preventive actions in order to control any poor performance. It is obvious that in subsequent periods the trend of progress by EV metrics can be traced accordingly. In this regard, bottlenecks must be identified and prevented from reoccurrence in the upcoming processes. By this reasoning, a cause and effect diagram can also be elaborated in order to identify the root causes of issues happened in the shop floor to analyze them for future. Also, other strategies can be proposed by the managers involved, e.g., using overtime for production staff.

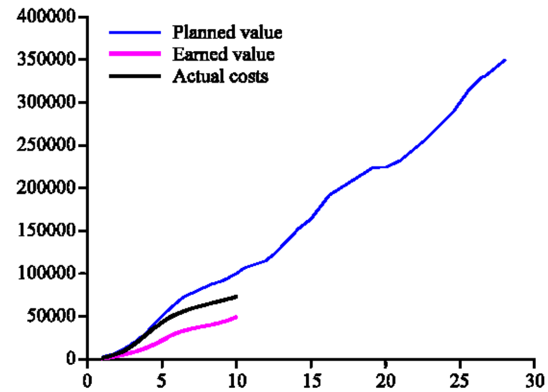

Fig. 4: EV analysis

The horizontal axis shows days and the vertical one represents the total costs.

Forecasting new budget/time to be delivered to the customer: Since the EV method represents schedule and cost performance indices based on the achieved progress, it is also possible to present a forecast for on time and specially budget required at completion. It is pointed out that forecasting results will be updated periodically just at the end of each control period. This helps the manufacturer to monitor progress trend during manufacturing processes and demonstrate output or achieved results accordingly.

Based on the planned value method (Anbari, 2003) planned value rate for each week is equal to BAC/PD, where BAC and PD indicate budget at completion and planned duration. Therefore, the planned value rate is almost 12500. In other words, schedule variance arises due to the difference between EV and planned value. By dividing the schedule variance by planned value rate (50,000/12500) a four weeks slippage can appear due to obtained performance. This implies that the actual achievement in comparison with the initial planned delivery performance will reach the customer with 4 weeks delay.

In order to forecast estimate at completion cost (EAC) the following formula can be efficiently used (Al-Tabtabai and Diekmann, 1992):

$$EAC = ACWP_{Cum} + \frac{(BAC - BCWP_{Cum})}{CPI} \quad (4)$$

In this case, almost 515000 will be estimated as the amount required at completion. The manufacturer in this case must thus focus on weakness in order to make corrective actions otherwise profit margins will decrease. It is also possible to apply other forecasting formulae based on manufacturing strategy and performance (Al-Tabtabai and Diekmann, 1992; Anbari, 2003).

CONCLUSION REMARK AND FURTHER RESEARCH

This study not only addressed a control mechanism during implementation of manufacturing process, but also provided a forecasting in each period of manufacturing control based on pervious performance achieved in production environment.

The approach can be efficiently used in manufacturing processes where a manufacturer intends to ensure there is enough time/cost in order to achieve on time-on budget delivery performance to the customer.

In case of bad EV metrics, it is desired to apply time-cost trade off models in order to meet delivery due date. However, in this case, integration of those models embedded with production environments is planned for further research.

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