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Research Note

A master production schedule warning approach for cement equipment manufacturing enterprises

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Abstract. Reducing product delivery time is a key factor for enterprises in increasing their core competitiveness. In order to resolve problems, including lack of a warning and monitoring system for Master Production Schedules (MPS) in cement equipment manufacturing enterprises, we propose a warning mechanism based on theoretical finish percentage and actual finish percentage. First, an MPS model, based on the product Manufacturing Bill Of the Material (MBOM), is proposed. Second, we present an approach for generating planned time, actual time, actual finish percentage and theoretical finish percentage, and yellow and red warnings are introduced to evaluate whether the production plan is normal or not. Finally, we use an example to illustrate the proposed algorithm process. Experimental results have shown that the proposed approach is able to support MPS warning.

1. Introduction

With the rapid development of scientific technology, global competition is become more and more fierce. Reducing product delivery time is a key factor for enterprises in increasing their core competitiveness [1]. Since cement equipment is large and complex and the production cycle is long, production delays for a part or component would affect the whole project delivery time. Consequently, it is necessary to control the production schedule [2].

A Master Production Schedule (MPS) is a production plan at each specific time for each specific product. The classical approach for generating MPS assumes known demands, infinite capacity, and fixed processing times. Vargas et al. [3] developed a Probabilistic Dynamic Lot-size Algorithm (PDLA) to produce a procedure for creating an MPS. Hernández et al. [4] put forward a reference model to minimize total costs generated by production plans, considering production, inventory and capacity levels. Körpeolu et al. [5] presented a multi-stage stochastic programming approach in MPS. These approaches, mentioned above, make the production schedule more agile and visual. However, they fail to consider whether the MPS can be finished in time, the reason for which is the lack of warning and monitoring for the MPS in production.

With the development of computer information technology, data acquisition approaches are widely used to visually warning system [6-8]. In consideration of the excellent characteristics of data acquisition approaches, two early warning mechanisms, based on theoretical finish percentage and aural finish percentage, in the MPS system, are presented for cement equipment

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manufacturing enterprises. Using MPS early warning mechanisms, production delay could be displayed directly; managers can find the problem in production and update the production plan for ensuring delivery time.

The rest of the paper is organized as follows. First, a brief review of the related literature is presented in Section 2, and the development approach and features of the MPS for cement equipment manufacturing enterprises are presented in Section 3. Then, we develop a red and yellow warning mechanism for MPS in Section 4, and the calculation methods of the thresholds are analyzed in Section 5. Following this, we use an example to illustrate the proposed algorithm process in Section 6, and, finally, the paper ends with some conclusions in Section 7.

2. Literature review

The literature regarding early warning systems is very rich. In the following, we give a brief overview of them. Xu et al. [9] put forward a fault early warning method for equipment management, based on ant colony clustering. Sun et al. [10] proposed an early warning mechanism based on a grey model for the equipment performance information collected by a SNMP-based network management system. Cristina et al. [11] proposed a EWS, based on wireless sensor networks, which has a reputation for controlling network behavior. Arab et al. [12] proposed an early warning method to comprehensively monitor the effects of each possible schedule on the throughput of the production system, so as to guarantee operational productivity and scheduling efficiency. The literature mentioned above mostly focuses on adopting algorithms to realize the early warning mechanism. There is little literature available regarding the differences and interconnections of warning details in complicated early warning systems.

The early warning forms are very important, for they can show the current situation of the system. Xiang and Wen [13] adopted the technology of the internet to monitor real-time traffic conditions, and early warning was realized by the curve simulated by the data. Sun et al. [14] proposed an early warning method based on web form, and font color, such as blue and red, can monitor whether the production process is in a control state. López et al. [15] developed an early warning system based on neural networks. In their system, different colors show the meanings of the different warnings: green or grey represents normal, orange represents warning and red or brown represents alert. The early warning forms can help management personnel to get warning information, but they fail to involve the measures and reasons for the warnings.

3. MPS in cement equipment manufacturing enterprises

The MPS in cement equipment manufacturing enterprises is very complicated, due to the development, modification, examination and approval of the MPS involved in the coordination and cooperation of all departments in the enterprise. A reasonable MPS will increase the largest gains and improve the utilization rate in the company.

Make-to-order is the usual mode for cement equipment manufacturing enterprises, so, the purchase and production are arranged after the order has been determined. The project is the main line of the MPS, all projects should be used to generate the MPS for ensuring product delivery time, and the project cannot be removed until it is finished [2]. The managers can adjust one project design time, production time, purchasing time and production time to guarantee all MPS delivery times.

In this paper, according to the characteristics of cement equipment production, we propose an MPS model based on the Manufacturing Bill Of Material (MBOM), which takes the project as a unit. An example of the MBOM is given in Table 1 in which, product name, material list and serial number, like "1.1" and "1.1.2", are shown. Here, the serial number represents the hierarchy relation between the components and parts, and the material ID and process ID, respectively, represent the purchasing tasks and the detailed production tasks.

The MPS includes four time periods in Figure 1, such as product design cycle, technological preparation cycle, key parts purchasing cycle, and main components process production cycle. The four time periods have different, important degrees. For example, when the design cycle has been finished, the task's completed progress is 20%, and when the technological preparation cycle has been finished, the task's completed progress is 50%.

Elements of the MPS mainly contain the levels ID, task name, numbers, bill, production team, dispatch-

Table 1. An example of product MBOM.

Levels ID	Parts name	Material ID	Process name	Process ID
1	A	-	-	-
1.1	B	-	-	-
1.2.1	C	01.01.000001	-	-
1.2.2	D	01.07.000001	-	-
1.2.2.1	-	-	welding	001
1.2.2.2	-	-	machine	002
...	...	...	...	...

Table 2. The element of the MPS.

Levels id	Task name	Number	Production team	Planned start time	Actual start time	Planned finish time	Actual finish time	Finish percentage
1	Project 1							
1.1	Half tooth	1		2012-7-24	2012-7-24	2012-9-24	2012-9-28	100
1.1.1	Half tooth (design)		Design department	2012-7-24	2012-7-24	2012-8-1	2012-8-2	100
1.1.2	Half tooth (technology prepare)		Technology department	2012-7-24	2012-7-25	2012-8-5	2012-8-6	100
1.1.3	Half tooth blank (purchasing)		Purchase department	2012-7-24	2012-7-27	2012-8-24	2012-8-26	100
1.1.4	Half tooth (production)		Production department	2012-7-24	2012-7-28	2012-9-24	2012-9-25	100
1.2	...		...	...	...	...	...	...
1.2.1	...		...	...	...	...	...	...

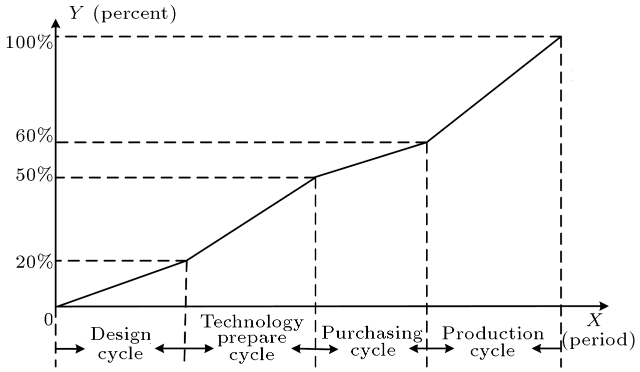


Figure 1. The four cycles of the MPS.

ers, planned start time, planned finish time, actual start time, actual finish time, and finish percentage. The tasks mainly contain three levels: the project, the key parts and the bottom tasks. The bottom tasks are composed of the key parts' four cycles (Table 2). In Table 2, basic information of the production process is fed back to the managers by a kind of billboard mode.

4. MPS warning mechanism in cement equipment manufacturing enterprises

In order to find problems in the production process and control the project's dynamic progress, we need to establish an early warning mechanism. The warning mechanism has four basic elements: planned time, actual production time, actual finish percentage and theoretical finish percentage.

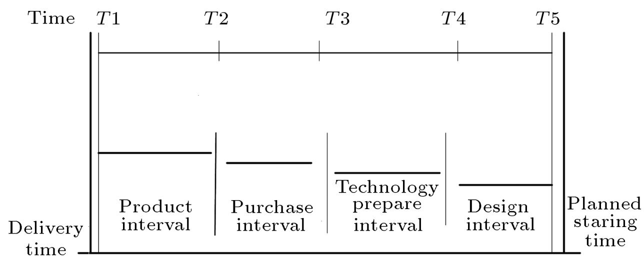


Figure 2. The four cycles' interval.

4.1. Predict the planned time of the MPS

In cement equipment manufacturing enterprises, they usually have the same equipment and the same influencing factors. Therefore, the intervals of four periods usually have few fluctuations. Based on these characteristics of the cement equipment, bottom tasks, like the planned production time node, are usually set by adopting the back scheduling method. In this approach, the production delivery time is set as the starting point, while the four period's start time and finish time is set by moving forward in turn (see Figure 2).

When the planned start time and planned finish time of the bottom tasks are worked out, the planned start time and planned finish time of the key parts are the latest time of its bottom tasks, and the planned start time and planned finish time of the project are the latest time of the key parts. When the planned time in the bottom tasks is changed, the corresponding planned time of the parts and project should be updated, too.

4.2. Generate the actual production time

In this paper, we assume that the actual start and actual finish times of the bottom tasks in the MPS are maintained by the employees. Similar to planned time, the key parts' actual finish time is the latest finish time of its four cycles, while the project's finish time is the latest finish time of its key parts.

4.3. Generate the actual finish percentage

Here, the finish percentage of the key parts is generated by the four bottom tasks' actual percentage, and the project's finish percentage is generated based on the weighted average method from the key parts. Detailed steps are given in the following.

Step 1. Get the indexes of the bottom and upper tasks of the MPS. The indexes can be represented by Eqs. (1) and (2) in the following:

$$\text{BIndex}\ (n) = \text{index}\ (\text{level\_id}, n), \tag{1}$$

$$\text{UIndex}\ (n) = \text{index}\ (\text{level\_id}, n-1). \tag{2}$$

Here, BIndex (n) and UIndex (n) are, respectively, the task n's bottom index and upper index, and, when BIndex (k) = UIndex (n), it means that there are hierarchy relations between task k and task n.

Step 2. Calculate the key parts' finish percentage. The four time periods have different influences on the key part's percentage if the key parts are different. In this paper, we calculate them by Eq. (3) in the following:

$$p_k = \sum_{i=1}^{4} w_{ki} m_{ki}, \quad \sum_{i=1}^{4} w_{ki} = 1; \quad i, k \in N. \tag{3}$$

Here, p_k is the kth part's finish percentage, w_{ki} is the ith period percentage benchmark of the kth part, m_{ki} is the ith period's actual finish percentage of the kth part. When the four cycle's benchmarks are set, the part's finish percentage can be calculated. For example, let the design cycle's benchmark be 20%. If the design cycle has been finished, the part's complete percentage, p_k, is 20%. If 80% of the design cycle has been finished, the part's complete percentage, p_k, is 16%.

Step 3. Calculate the projects' finish percentage according to the key parts' finish percentage.

In cement equipment manufacturing enterprises, the quantity of the parts is a key element, especially for larger parts. So, the quantity of parts is used to calculate the project's finish percentage. The calculation methods are described in Eq. (4):

$$P = \frac{1}{S_{\text{sum}}} \sum_{k=1}^{n} w_k q_k p_k. \tag{4}$$

Here, P is the project's finish percentage, n is the number of key parts in the project, w_k is the weight of the kth part, q_k is the kth part's quantity, p_k is the kth parts' finish percentage, and S_{sum} is the whole project quantity.

4.4. Generate the theoretical finish percentage

In this paper, we propose a theoretical finish process to describe the task's finish percentage under the planned time. The calculation formula of the ith task's theoretical finish progress, z_i, is given in Definition 1.

Definition 1. The theoretical finish progress is defined as:

$$z_i = \frac{\text{Getdate}\ (t_m, t_{i0})}{\text{Getdate}\ (t_n, t_{i0})}.$$

Here, t_m is the current time, t_{i0} is the ith task's actual start time, t_n is the ith task's planned finish time, Getdate (t_m, t_{i0}) is the time interval between the current time and the ith task's actual start time, and Getdate (t_n, t_{i0}) is the time interval between the planned finish time and the actual start time of the ith task.

4.5. MPS warning mechanism

In the operation of the enterprise, managers need to monitor the task's actual progress at all levels in time. Therefore, we need to dynamically analyze the whole project's progress. In this paper, we propose a red and yellow warning mechanism to monitor the problems of progress of the MPS.

In the actual production process, there must be deviation between the actual finish time and planned finish time. As shown in Figure 3, the black line represents the theoretical finish progress, while the red line represents the actual finish progress. Assume $X0$ is the current time, and $\zeta_0 = (Z0 - Y0)$ is the

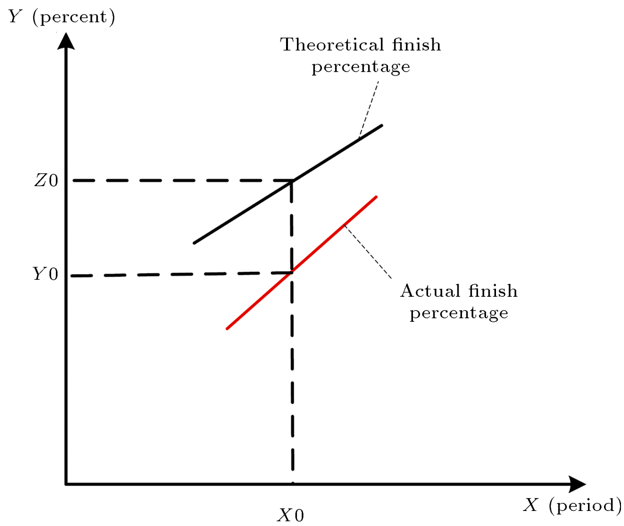


Figure 3. The deviation of the actual finish percentage and theoretical finish percentage.

corresponding deviation of theoretical finish percentage and actual finish percentage. The deviation's influence on the MPS is affected by the project delivery time and the scope of the theoretical finish percent in current time, and the influence is inversely proportional to the current time's theoretical finish percent and the time interval between the scope and the project delivery. In this paper, a threshold, Δ, is used to evaluate the deviation's influence and, then, to judge the warning level. Detailed calculation methods of the threshold are introduced in Section 5.

The ith task's threshold is Δ_i, and it is divided into two kinds, i.e. yellow warning lower threshold, Δ_{1i}, and red warning lower threshold, Δ_{2i}, and the value of the threshold is different when the theoretical finish percentage is in different time nodes. ζ_i is the deviation of theoretical finish percentage and actual finish percentage in the current time. So, the red warning mechanism and yellow mechanism, based on the deviation and threshold in current time, can be defined as follows:

Definition 2. Yellow warning mechanism. If the $\Delta_{1i} < \zeta_i < \Delta_{2i}$, we define that the ith task in MPS system appears yellow color.

Definition 3. Red warning mechanism. If the $\zeta_i \geq \Delta_{2i}$, the ith task in the MPS system appears in red.

5. Calculation methods of the thresholds

The early warning mechanism for MPS is used to ensure the delivery time. In Figure 4, the early warning will be more accurate if there are more monitor nodes among the theoretical finish percentage. Therefore, the larger the number of monitor nodes, the larger the system load.

Usually, in the early production, some production plan delays can be adjusted in the production process. If the planned finish time is near the delivery time, the production plan's delay would affect the product's delivery time. So, based on this characteristic of cement equipment production, 6 MPS monitor periods are proposed:

$$\{(0, 50\%), (50\%, 70\%), (70\%, 80\%),$$

$$(80\%, 90\%), (90\%, 100\%), (100\%, \infty)\}.$$

The yellow and red warnings have different thresholds in different monitor periods. Usually, the

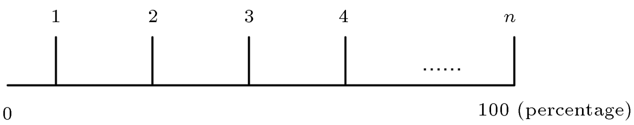


Figure 4. The MPS monitor nodes.

threshold can be confirmed by the history data and expert experience. The detailed steps are given in the following:

Step 1. Confirm the monitor periods and evaluation standards.

The evaluation standards can be divided into 3 types, i.e. few resources are needed to adjust the plan ($Q1$), more resources are needed to adjust the plan ($Q2$), and the delivery time would delay ($Q3$).

Step 2. Adopt expert experience to evaluate the standards.

Due to the complexity of the various factors and the fuzziness of human thought, it is difficult to use a precise number to make an evaluation. Generally, we use semantic words, such as very big, big, general, and small, to express the effect on the various standards. As shown in Figure 5, the attributes can be divided into six grades [16,17].

If the thresholds are divided into n types, and suppose there are m experts to evaluate the thresholds' evaluation standards. The evaluation methods are given in Figure 6. Here, E_{ij} present the ith expert's evaluation on the jth threshold, and E_{ij}'s fuzzy attribute values can be described as in Eq. (5):

$$E_{ij} = [E_{ij}^1, E_{ij}^n, E_{ij}^r]. \tag{5}$$

Here, E_{ij}^1, E_{ij}^n and E_{ij}^r, respectively, represent the fuzzy attribute's left value, middle value, and right value, and $E_{ij} \in S$, $S=$ {very small (VP), small (P), general (M), big (G), very big (VG), extremely big (E)}. The form of the triangular fuzzy number, which corresponds with the scale, can be expressed as follows:

$$\text{VP} = [0, 0, 1]; \quad P = [0, 3, 5]; \quad M = [1, 3, 5];$$

$$G = [3, 5, 7]; \quad \text{VG} = [5, 7, 9]; \quad E = [7, 9, 9].$$

Step 3. Calculate the thresholds of yellow and red warnings.

In this paper, we adopt the weighted average method to calculate the expert evaluation of the three

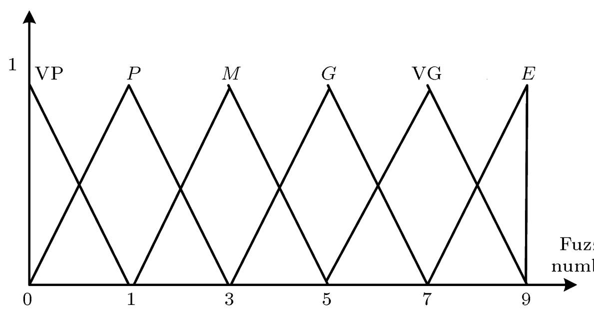
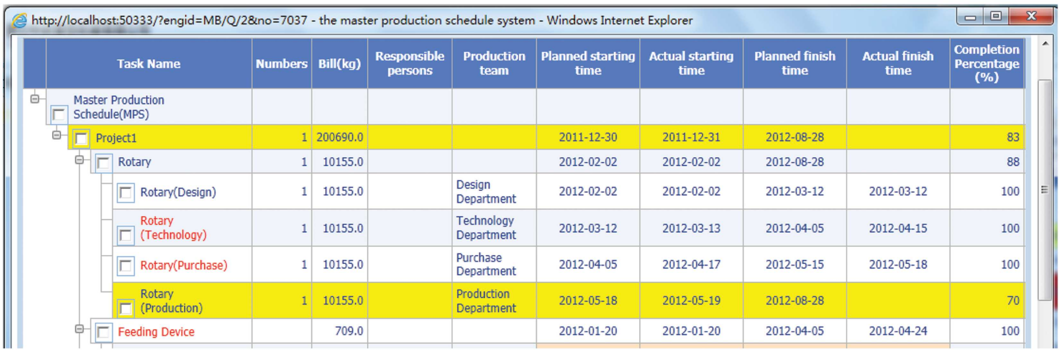


Figure 5. Attribute semantic variable.

Threshold value \ Experience evaluation \ Evaluation standards	Need little resources to adjust the plan ($Q1$)				Need more resources to adjust the plan ($Q2$)				Delivery time would delay ($Q3$)			
$Z0$	$E10$	$E20$	...	$Em0$	$E10$	$E20$	...	$Em0$	$E10$	$E10$	...	$Em0$
$Z1$	$E11$	$E21$	...	$Em1$	$E11$	$E21$	...	$Em1$	$E11$	$E21$	···	$Em1$
. . .			...				...				...	
Zn	$E1n$	$E2n$	...	Emn	$E1n$	$E2n$	...	Emn	$E1n$	$E2n$	...	Emn

Figure 6. Evaluation methods for the threshold value.


http://localhost:50333/?engid=MB/Q/2&no=7037 - the master production schedule system - Windows Internet Explorer

Task Name	Numbers	Bill(kg)	Responsible persons	Production team	Planned starting time	Actual starting time	Planned finish time	Actual finish time	Completion Percentage (%)
Master Production Schedule(MPS)									
Project1	1	200690.0			2011-12-30	2011-12-31	2012-08-28		83
Rotary	1	10155.0			2012-02-02	2012-02-02	2012-08-28		88
Rotary(Design)	1	10155.0		Design Department	2012-02-02	2012-02-02	2012-03-12	2012-03-12	100
Rotary (Technology)	1	10155.0		Technology Department	2012-03-12	2012-03-13	2012-04-05	2012-04-15	100
Rotary(Purchase)	1	10155.0		Purchase Department	2012-04-05	2012-04-17	2012-05-15	2012-05-18	100
Rotary (Production)	1	10155.0		Production Department	2012-05-18	2012-05-19	2012-08-28		70
Feeding Device		709.0			2012-01-20	2012-01-20	2012-04-05	2012-04-24	100

Figure 7. The MPS system.

standards for different thresholds. The calculation formula is given in Eq. (6):

$$E_{Z_m} = \frac{1}{n}\sum_{i-1}^{n}\tilde{E}_{ij}. \qquad (6)$$

Here, E_{Z_m} is the average value of the threshold, Z_m, and $\tilde{E}_{ij}$ is the triangular fuzzy value. For example, if there are five experts to evaluate the Z_m's value, and the evaluation values are $\{3,4,3,5,6\}$, then, the average value is:

$$E_{Zm} = \frac{1}{5}\sum_{i=1}^{5}\tilde{E}_{ij} = \frac{1}{5}(3+4+3+5+6) = 4.2.$$

Then, the threshold which has the biggest evaluation value under evaluation, $Q2$, is the threshold of the yellow warning, and the threshold which has the biggest evaluation value under evaluation, $Q3$, is the threshold of the red warning.

6. Case for the MPS warning approach

A project is used to illustrate the MPS warning approach combined with the cement manufacturing equipments' actual management. The MPS system is given in Figure 7, and the main tasks contain the feeding device, rotary, and so on. The planned start and finish times at all level tasks have been worked out, according to experience and historical data. The actual start time and finish times in the bottom's task are updated by the relevant employers, and the upper tasks' actual start and finish times are calculated by the weighted average method.

The ith task's early warning mechanisms are divided into six kinds, when the values of the theoretical finish percentage (z_i) are different according to the experience and characteristics of the cement equipment manufacturing enterprise. The six kinds are described as follows:

1. $0 < z_i \leq 50\%$.
   If the red warning threshold, Δ_{2i}, is 40, when $\zeta_i \geq 40\%$ occurs, the ith task in the MPS appears as a red warning.
2. $50\% < z_i \leq 70\%$.
   If the yellow warning threshold, Δ_{1i}, and red warning threshold, Δ_{2i}, are, respectively, 20% and 40%, when $20\% < \zeta_i < 40\%$, the ith task in the MPS appears as a yellow warning, and when $\zeta_i \geq 40\%$, the ith task in the MPS appears as a red warning.

3. $70\% < z_i \leq 80\%$.
   If the yellow warning threshold, Δ_{1i}, and red warning threshold, Δ_{2i}, are, respectively, 15% and 30%, when $15\% < \zeta_i < 30\%$, the ith task in the MPS appears as a yellow warning, and when $\zeta_i \geq 30\%$, the ith task in the MPS appears as a red warning.
4. $80\% < z_i \leq 90\%$.
   If the yellow warning threshold, Δ_{1i}, and red warning threshold, Δ_{2i}, are, respectively, 10% and 20%, when $10\% < \zeta_i < 20\%$, the ith task in the MPS appears as a yellow warning, and when $\zeta_i \geq 20\%$, the ith task in the MPS appears as a red warning.
5. $90\% < z_i \leq 100\%$.
   If the yellow warning threshold, Δ_{1i}, and red warning threshold, Δ_{2i}, are, respectively, 5% and 10%, when $5\% < \zeta_i < 10\%$, the ith task in the MPS appears as a yellow warning, and when $\zeta_i \geq 10\%$, the ith task in the MPS appears as a red warning.
6. $z_i > 100\%$.

The ith task in the MPS appears as a red warning.

6.1. Early warning approach with the deviation

If the current time is Aug. 10, 2012, the system shows a warning for the all level tasks.

The bottom task warning. According to Definition 1, the theoretical progress of the 6th task (rotary (production)) in the current time is:

$$Z_6 = \frac{\text{Getdate }(t_m, t_{60})}{\text{Getdate }(t_n, t_{60})}$$

$$= \frac{\text{Getdate }(2012.8.10, 2012.5.19)}{\text{Getdate }(2012.8.28, 2012.5.19)} = 87\%,$$

Actual progress is $Y_6 = 70\%$, deviation is $\zeta_6 = Z_6 - Y_6 = 17\%$, thresholds is $\Delta_{16} = 15\%$, and $\Delta_{26} = 30\%$. Because $15\% < \zeta_6 < 30\%$, the 6th task in the MPS appears as a yellow warning.

The key parts warning. The theoretical progress of the 2nd task (rotary) in the current time is:

$$Z_2 = \frac{\text{Getdate }(t_m, t_{20})}{\text{Getdate }(t_n, t_{20})}$$

$$= \frac{\text{Getdate }(2012.8.10, 2012.2.2)}{\text{Getdate }(2012.8.28, 2012.2.2)} = 91.3\%.$$

According to Eq. (3), the key part's actual finish percentage is $p_2 = \sum_{i=1}^{4} w_{2i} m_{2i}$, and if the benchmarks of the four cycle are 20%, 10%, 30% and 40%, respectively, then, the actual finish percentage is:

$$Y_2 = p_2 = \sum_{i=1}^{4} w_{2i} m_{2i}$$

$$= 0.2 + 0.1 + 0.3 + 0.4 \times 0.7 = 88\%.$$

Deviation is $\zeta_2 = Z_2 - Y_2 = 3.3\%$, and thresholds are $\Delta_{12} = 5\%$ and $\Delta_{22} = 10\%$. Because $\zeta_2 < 5\%$, the 2nd task in the MPS is normal.

The project warning. The project's theoretical progress in the current time is:

$$Z_1 = \frac{\text{Getdate}(t_m, t_{10})}{\text{Getdate}(t_n, t_{10})}$$

$$= \frac{\text{Getdate}(2012.8.10, 2012.12.31)}{\text{Getdate}(2012.8.28, 2012.12.31)} = 92.5\%,$$

According to Eq. (4), the project's actual finish percentage is $P = \frac{1}{S_{\text{sum}}} \sum_{k=1}^{n} w_k q_k p_k = 83\%$.

Deviation is $\zeta_1 = Z_1 - Y_1 = 9.5\%$, and threshold $\Delta_{11} = 5\%$ and $\Delta_{21} = 10\%$. Because $5\% < \zeta_1 < 10\%$, the 1st task in the MPS appears as a yellow warning.

6.2. Results

Based on the early warning mechanism, if the system shows as a yellow or red warning, the relevant departments can take corresponding measures to ensure product delivery time.

7. Conclusions

We present an MPS warning approach for cement equipment manufacturing enterprises in this research. The experimental results have shown that the proposed method can improve the efficiency of a production schedule. This approach can help managers to find the production delay problem using red and yellow warning mechanisms. However, there are still some limits to the proposed approach, such as setting weight. In the future, we will adopt some optimal algorithms to set weights instead of using expert knowledge.

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