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ABSTRACT

This paper discusses about a management tool for effective project progress. Considered issue in this paper is a problem to estimate rational duration of each elementary operation for meeting final due completion time of a project. An effective procedure is proposed for this purpose that includes decision tree analysis, Bayes formula and particular iterative probability calculation. Three cases were examined to analyse the characteristics of the proposed procedure and it was clarified that this procedure provide a powerful support function for project planning and progress activities in the era of IT-oriented business environment, where the right timely decisions are critical.

INTRODUCTION

Project management technology such as PERT/CPM has been widely used for realising efficient activities of product development, large-scale production such as shipbuilding and project planning/management in engineering to order manufacturing industries *etc.* This technology mainly aims to maximise the probability to meet the specified deadline and to identify which operation is the most likely to be the bottleneck based on a concurrent engineering context.

In the actual operation processes, this technology is used for both initial planning phase and recovery phase during the term that project is proceeded. The former case has been dealt with the kernel of PERT/CPM logic, *i.e.* algorithm for detection of the critical path and the latter have been tackled by more business oriented software based on the work break down structure. However, in a current volatile and competitive environment driven by the diversification of e-business, guaranteeing the given completion date accurately, quick re-scheduling for recovery of delay or adaptation to change of business environment, *e.g.* due date change, trouble on project resource procurement, and development of technology enabling to cope with these problems are becoming more and more critical than the past.

For recovery of delay or adaptation to change of business environment, one possible method is re-allocation of operation resources such as labour, tools, materials etc. There are many mathematical models and/or procedures for rational resource allocation, especially in case of allocation of human-hour resources in hand[1], [3]. These mainly aim to minimise expected project duration or to meet the planned due date at the starting point of a project. However, in reality, it is not easy, even at the initial stage, to provide a rational resource assignment for a given due date especially in a fragile business environment such as stochastically fluctuated processing time. Also, it is problem-some for a dynamic situation such as due date change, delay of schedule due to lack of operation resources. Therefore, these conventional technologies are less relevant in such situations.

On the other hand, guaranteeing Just-In-Time completion of the project in a volatile business environment such as stochastic fluctuation of processing time is tackled by a research paper [4], [5]. The procedure discussed in the paper is an estimation method of duration distribution of each elementary operation for meeting planned project due date and it was recommended to use this distribution for design of improved method of each elementary operation to realise more accurate completion. However, it is still on the middle point to identify exact target processing time of each elementary operation by rational way, which is certainly necessary for effective progress management to meet entire project due date.

A schematic procedure proposed in this paper provides a solution to such research theme. The considered problem is how to determine rational target operation duration of each elementary operation for meeting final due completion date of the project under uncertain processing time environment. This problem is of rather microscopic view. However, it is critical because project manager is always asked to actualise sound project progress. In a volatile environment characterised by stochastically fluctuated operation time and frequent due date changes by various reasons, the effective procedure to guarantee Just-In-Time completion of the project is an essential weapon in a current competitive market. To cope with this tough mission, a methodology for targeting the duration of arbitrary elementary operation of the project is developed by using decision tree analysis and Bayes formula. Some example calculations are also performed to validate the proposed procedure.

METHOD OF SETTING OBJECTIVE TIME DURATION

In this section, above-mentioned rational determination procedure of target duration of each elementary operation for meeting entire project due date under uncertain processing time environment is proposed.

Figure 1 illustrates the step-wise procedure proposed in this paper to cope with this requirement. The well-known Decision Tree Analysis [7] and Bayes formula [6], [2] are deployed in step 2 and 3 to deduce posterior probability distribution of each elementary operation' s duration. Step 1 relates to a progress management policy, and step 4 and 5 are an evaluation module of accuracy of expected project completion date. Step 6 is preparatory procedure for improving its accuracy and step 3, 4, 5 and 6 will be iterated until probability of expected project duration saturates. In actual progress management can be performed based on the derived target process time of each elementary operation.

The following description is to compensate the proposed procedure. Namely, the problem how to estimate the duration of each elementary operation under the restriction of given entire project duration can be considered through the network representation of the considered project.

Figure 2 illustrates a simple example project represented by activity-on-arrow (AOA) network form.

Probability distribution of the entire project duration can be obtained through application of decision tree analysis illustrated in Figure 3 to this network system. That is, firstly, every possible path is encountered and represented in terms of tree structure. Then, secondly, possible entire duration and its probability are evaluated through simple probability operations.

Subsequent procedure is duration estimation of each elementary operation under the condition of given entire project duration given in the step 3. This estimation can be realised by using Bayes formula expressed in (1). This formula converts prior probability distribution of each elementary operation to its posterior distribution under the restriction of given entire project duration. In this procedure, X_i or X_k in the right hand side of equation (1) denotes prior probability of the event that duration of elementary operation X is equal to i or k. Y in the right and left hand side of equation (1) denote target entire project duration. On the other hand, X_k in the left hand side of equation (1) is prior probability of the event that duration of elementary operation X is equal to k.

<Bayes formula>

$$P(X_k \mid Y) = \frac{P(X_k \cap Y)}{P(Y)} = \frac{P(Y \mid X_k)P(X_k)}{\sum_i P(Y \mid X_i)P(X_i)} \qquad (1)$$

Where, X_i: Mutually exclusive events, which cover the considered sample space Ω

$P(X_i) > 0, (i = 1,2,\cdots)$

Y: Conditional event $P(Y) > 0$

CASE CALCULATION

1) A case of small-scale project

As an example project, a network of which structure is simple but essential with six operations *i.e.* A, B, C, D, E and F is considered (See Figure 4). This network has three operation paths *i.e.* ABD, CD and EF, of which the maximum length path determines the critical path.

Duration of each elementary process is supposed to be stochastically fluctuated with time distribution given in Table 1 and the target entire project duration is supposed to be 16 time units.

Applying the proposed procedure described in Figure 1 to these data, target time of each elementary operation is obtained, which is summarised in Table 2.

From this result, it is noticed that path 1 is the critical path as every posterior distribution of elementary operation included in the path 1 saturated to each particular point. Other elementary operation such as operation C in the path 2 has ordinary posterior distribution, which means this operation has a slack enabling to vary its duration between 6 to 10 time units. Saturation point of distribution of each operation tends to be the point of biggest prior probability within a distribution (See elementary operations B and D in path 1). However, sometimes it saturates to the point with least prior probability such as operation A. In this case, progress management system has to ask concerned correspondent to aim the least likely duration and this makes difficulty of the management.

2) More complicated project

Next example is more complicated project with five paths to reach the completion state from starting point and nine operations *i.e.* A, B, C, D, E, F, G, H and I (See Figure 5).

The target entire project duration is supposed to be 12 time units. Also, duration of each elementary process is supposed to be stochastically fluctuated with time distribution given in Table 3. The feature of this network is that elementary operation B has almost singular distribution, i.e. probability is concentrated on duration 6 (See shadowed cell in Table 3).

Applying the proposed procedure to these data, target time of each elementary operation is obtained, which is summarised in Table 4.

From this result, it is noticed that posterior distributions of three elementary operations included in the path 3, which has operation B with almost singular distribution, saturated to each particular point. This means path 3 may be the critical path. As a remarkable issue, especially, it is suggested that operation B should have duration 6 (See shadowed cell in Table 4) for Just-In-Time completion of this project and this message has no contradiction with given singular-like distribution. The other particular phenomenon is that distribution of operation D also saturated to particular point, i.e. duration 2 (See shadowed cell in Table 4), which is not on the critical path.

It is noticed from these results that more intricate phenomena can be observed if network becomes complicate. These phenomena are difficult to expect subjectively and, therefore, the proposed calculation method has its meaning although calculation becomes tedious according to complexity increase.

3) Special project

The last example is simpler but more delicate project with two paths and three operations *i.e.* A, B and C (See Figure 6).

The target entire project duration is supposed to be 9 time units and duration of each elementary process is supposed to have time distribution given in Table 5. Then, applying the proposed procedure to these data, obtained target time of each elementary operation is summarised in Table 6. The result shows that expected probability of entire project duration do not saturate to one and posterior distribution of each operation is not improved by iteration. Table 6 gives concerned distributions of this situation.

From this result, it is noticed that no prior distribution can saturate to a particular point. This means that either the case of duration of operations A = 3 time units and C = 6 time units or the case of duration of operations A = 4 time units and C = 5 time units can meet the target entire project duration, i.e. 9 time units. Obviously, these cases occur with probability 0.5 and if one of these conditions is satisfied, target project duration can be attained. Namely, this phenomenon can be interpreted as existence of some degree of freedom on the way of progress management.

CONCLUDING REMARKS

In this paper, a methodology for estimating a rational duration of each elementary operation of a project was developed for its successful progress management, i.e. meeting its final due completion time, and its characteristics was examined by computer-based quantitative analysis. Obtained results from example calculations indicate that probability distribution of each elementary operation given as prior distribution can be saturated to a particular point in most case and, therefore, progress manager can assign resultant time durations as target duration of each elementary operation. In this sense, it can be notified the proposed procedure provide a powerful support function for project planning and progress activities in the era of IT-oriented business environment, where the right timely decisions are critical.

ACKNOWLEDGEMENTS

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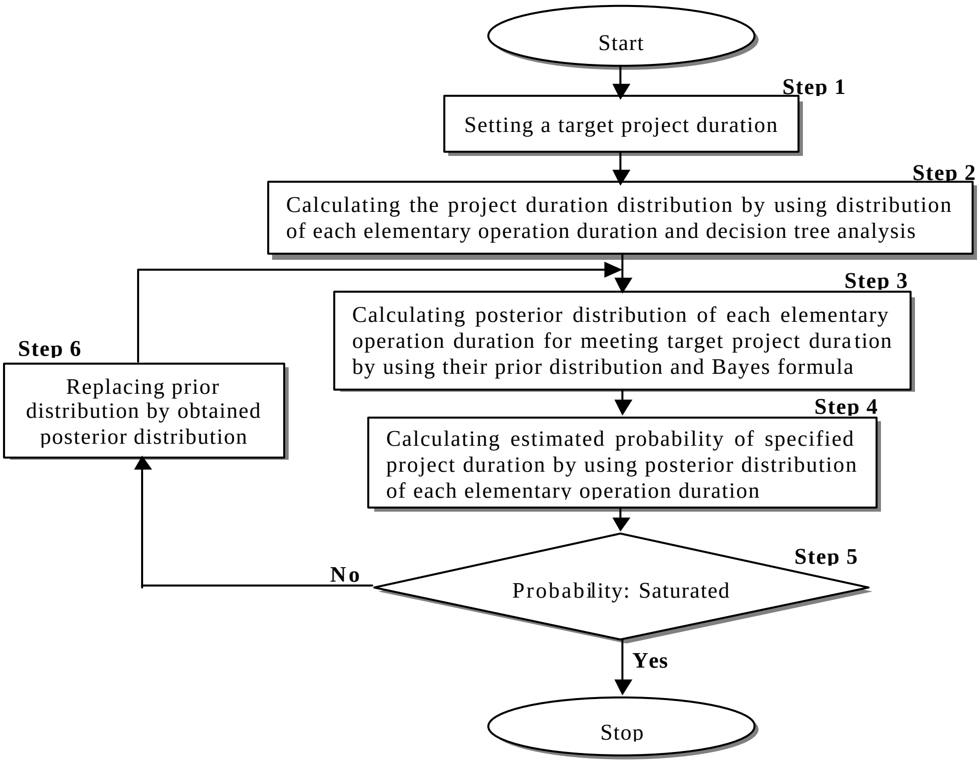

Figure 1. Method of setting objective time duration

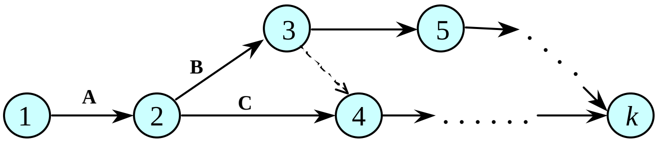

Figure 2: An example of activity-on-arrow (AOA) project network [1]

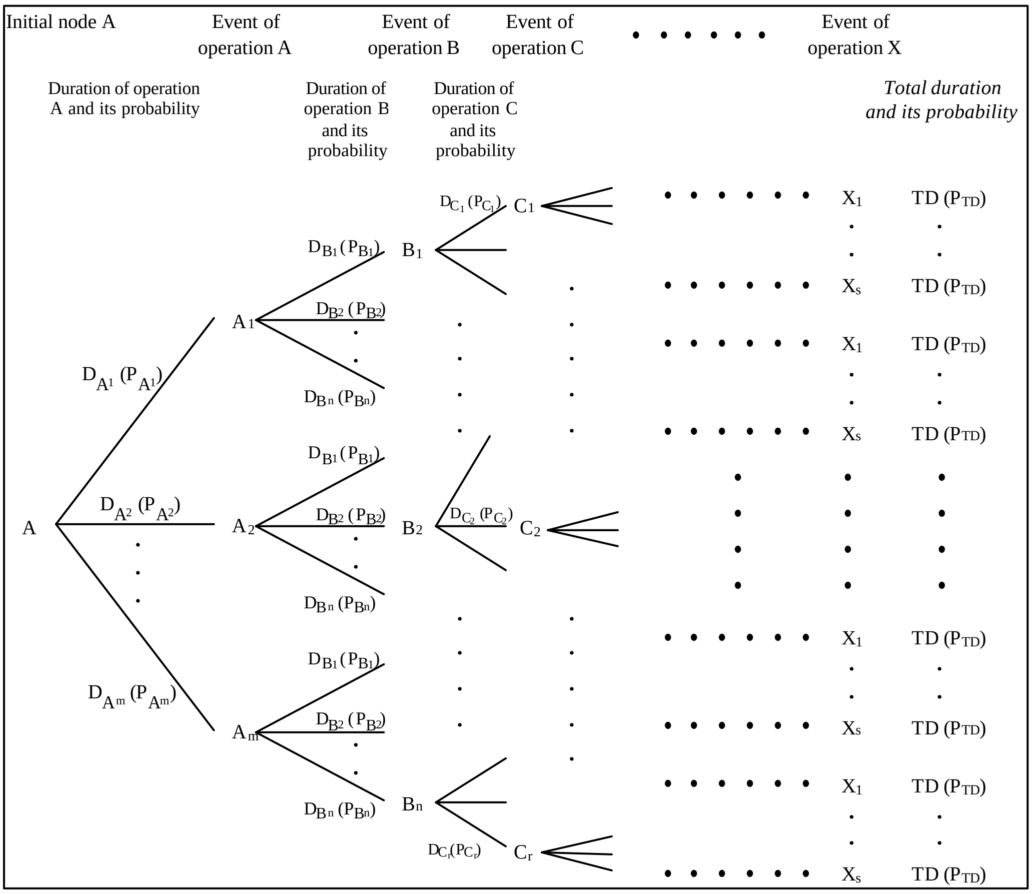

Figure 3. Decision tree analysis for probability estimation of total project duration

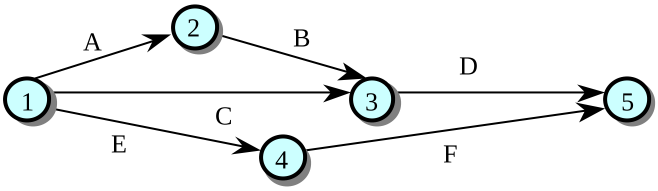

Figure 4. Project model 1 (a small scale project: AOA representation)

Table 1. Prior time distribution of elementary operation on each path

Time duration		2	3	4	5	6	7	8	9	10
Path1	EO: A	0.15	0.45	0.25	0.15	—	—	—	—	—
	EO: B	—	0.1	0.25	0.55	0.1	—	—	—	—
	EO: D	—	0.05	0.15	0.3	0.5	0.15	0.05	—	—
Path 2	EO: C	—	—	—	—	0.05	0.15	0.6	0.15	0.05
	EO: D	—	0.05	0.15	0.3	0.5	0.15	0.05	—	—
Path 3	EO: E	—	—	0.05	0.3	0.6	0.05	—	—	—
	EO: F	—	—	0.1	0.15	0.2	0.3	0.2	0.1	—

EO: Elementary Operation

Table 2. Target time distribution of elementary operation on each path

Time duration		2	3	4	5	6	7	8	9	10
Path1	EO: A	0	0	0	1	—	—	—	—	—
	EO: B	—	0	0	1	0	—	—	—	—
	EO: D	—	0	0	0	1	0	0	—	—
Path 2	EO: C	—	—	—	—	0.0028	0.0084	0.0434	0.0285	0.9189
	EO: D	—	0	0	0	1	0	0	—	—
Path 3	EO: E	—	—	0.0484	0.2782	0.5585	0.1189	—	—	—
	EO: F	—	—	0.0883	0.1325	0.1767	0.2649	0.1767	0.1609	—

EO: Elementary Operation

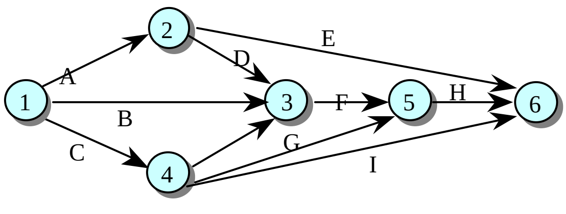

Figure 5. Project model 2 (more complicated project)

Table 3. Prior time distribution of elementary operation on each path

Time duration		2	3	4	5	6	7	8	9
Path1	EO: A	—	0.2	0.6	0.2	—	—	—	—
	EO: E	—	—	—	—	0.2	0.6	0.2	—
Path 2	EO: A	—	0.2	0.6	0.2	—	—	—	—
	EO: D	0.2	0.6	0.2	—	—	—	—	—
	EO: F	—	0.2	0.6	0.2	—	—	—	—
	EO: H	0.2	0.6	0.2	—	—	—	—	—
Path 3	EO: B	—	—	—	—	0.98	0.01	0.01	—
	EO: F	—	0.2	0.6	0.2	—	—	—	—
	EO: H	0.2	0.6	0.2	—	—	—	—	—
Path 4	EO: C	0.2	0.6	0.2	—	—	—	—	—
	EO: G	—	—	—	0.2	0.6	0.2	—	—
	EO: H	0.2	0.6	0.2	—	—	—	—	—
Path 5	EO: C	0.2	0.6	0.2	—	—	—	—	—
	EO: I	—	—	—	—	—	0.2	0.6	0.2

EO: Elementary Operation

Table 4. Target time distribution of elementary operation on each path

Time duration		2	3	4	5	6	7	8	9
Path1	EO: A	—	0.6253	0.3747	0	—	—	—	—
	EO: E	—	—	—	—	0.1452	0.4356	0.4192	—
Path 2	EO: A	—	0.6253	0.3747	0	—	—	—	—
	EO: D	1	0	0	—	—	—	—	—
	EO: F	—	0	1	0	—	—	—	—
	EO: H	1	0	0	—	—	—	—	—
Path 3	EO: B	—	—	—	—	1	0	0	—
	EO: F	—	0	1	0	—	—	—	—
	EO: H	1	0	0	—	—	—	—	—
Path 4	EO: C	0.0193	0.9807	0	—	—	—	—	—
	EO: G	—	—	—	0.1538	0.4330	0.4132	—	—
	EO: H	1	0	0	—	—	—	—	—
Path 5	EO: C	0.0193	0.9807	0	—	—	—	—	—
	EO: I	—	—	—	—	—	0.0550	0.1772	0.7678

EO: Elementary Operation

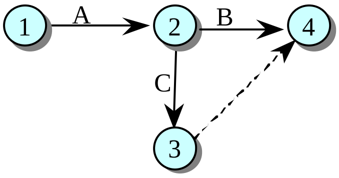

Figure 6. Project model 3 (special project)

Table 5. Prior time distribution of elementary operation

Time duration	2	3	4	5	6	7
Elementary operation A	0.25	0.5	0.25	-	-	-
Elementary operation B	0.25	0.5	0.25	-	-	-
Elementary operation C	-	-	0.25	0.5	0.25	-
Time duration	6	7	8	9	10	11
Project duration	00625	0.25	0.375	0.25	0.0625	-

Table 6. Target time distribution of elementary operation

Time duration	2	3	4	5	6	7
Elementary operation A	0	0.5	0.5	-	-	-
Elementary operation B	0.25	0.5	0.25	-	-	-
Elementary operation C	-	-	0	0.5	0.5	-
Time duration	6	7	8	9	10	11
Project duration	0	0	0.25	0.5	0.25	-