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Research on Complex Product WBS Process Simulation and Prediction

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Abstract: According to the uncertain and iterative characteristics during Work Breakdown Structure (WBS) process of complex product projects, a simulation model which is based on two-layer design structure matrix is proposed. The model takes into account the overlapping iterations, sequential iterative during WBS process, using the overlapping probability, rework probability, rework impact probability to describe the iterative characteristic of WBS, gives the corresponding simulation algorithm to multi task rework execution constraints, resource constraints. and then improved simulation algorithm of WBS process is proposed, designs and develops simulation platform of WBS process of complex product projects based on Matlab. Take a large ship enterprises as the research object, carries on the statistical analysis of simulation output data, estimates schedule and cost, to prove the validity and practicability of this simulation platform.

Key words: Work breakdown structure, design structure matrix, process simulation, iteration

INTRODUCTION

There's so many uncertain factors during the manufacturing process of complex products at the moment (Boysen and Fliedner, 2008) Work units which have been determined by Work Breakdown Structure (WBS) can't be used as a basis for effective project management (Li *et al*., 2011), the situations of activities overlap and activities iteration often occur. If managers improve quality by iteration, it will be easily lead to project delay and increase the cost and have more serious implications on consequences of unplanned iteration. If managers can use some methods to predict what will happen when the project runs, it is significant to make reasonable arrangement of project schedule and optimization of project process structure. Based on the uncertainty and iteration characteristics of complex product process, Fu *et al*. (2011) used Design Structure Matrix (DSM) model to predict the analysis of goal of cost and time. Through the combination of activity network and DSM model, Elmaghraby (2010) analyzed the risk factors, Cho and Eppinger (2005) captured the information flows where reworks take place among sequential parallel and overlapped tasks, Yang and Huang (2011) calculated duration time model based-on sequential overlapping and rework time mode based-on feedback overlapping. But the DSM lack of operability, it is a difficult to meet the requirement of integrity of information flow mechanism. These literatures don't take account of the fact that downstream tasks go ahead before upstream tasks ending and resource constraints. Through the literature review, if only depend on the existing analytical methods, WBS process can't be fully described and efficient analyzed. Considering combining process simulation and existing analytical can resolve this problem by analyzing performance indicators of WBS process, so that possible problems is predicted when project in order to ensure the successful implementation of WBS.

Based on previous researches, the DSM model which is more in line with the actual conditions is proposed. This rework situation takes tasks overlapping iteration and sequential iteration into account and considers the limitation of resource conflict. The simulation platform of WBS process is developed based on Matlab. It provides reference for every possible situation of WBS process in order to make a better decision for WBS process running.

ITERATIVE ANALYSIS OF COMPLEX PRODUCT MANUFACTURING PROCESS

The conventional DSM used deterministic way to describe the dependency between tasks. Because of the uncertainty dependent relationship of task units: On the one hand, whether the rework task happens is uncertain; on the other hand, if rework happens, the rework workload is also uncertainty. From the viewpoint of the causation, iteration are mainly classified into two types: overlapping iteration and sequential iteration.

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Overlapping iteration: Under the overlay mode, the downstream task started earlier upon obtaining a pre-release information from upstream task but due to the initial pre-release upstream tasks information is usually not perfect nor inaccurate and new information continues to produce and modifies, the downstream task is bound to part of the work of the upstream rework, then adds additional rework time and costs, both in the timeline formed a cross with overlapping or partially paralleled.

- **Overlapping rework amount matrix (ORAM):** Suppose the next phased-task unit "i" can not be earlier than phased-task unit "j" completed, the proportion of the overlapping rework matrix as ORA (i, j) (0, 1), (i, j = 1, 2,..., n) represents the task unit "i" and task "j" have temporal overlap. Matrix elements "0" indicates that the corresponding of two tasks without dependencies between units that can be fully executed in parallel while the matrix element is not "1" indicates that there is precedential relations between the task unit "i" and task unit "j"
- **Overlapping rework impact matrix (ORIM):** ORIM element ORI (i, j) represents workload of rework tasks unit "i" or the ratio of rework time accounted for its overlap. ORI (i, j) (0, 1), (i, j = 1, 2,..., n)
- Overlapping actual cost (OAC) = $C_i+C_i\times$ORR (i, j)$\times$ORI (i, j)
- Overlapping actual construction time (OACT) = $T_i+T_i\times$ORR (i, j)$\times$ORI (i, j)
- C_i is non-overlapping tasks planned cost of unit i, Ti is non-overlapping task unit "i" planned duration
- When the task is greater than equal to three overlapping: This study calculate respectively each overlapping cost and time; and then regard the maximum result which has calculated as time and cost of task unit.

Sequential iteration: The characteristic of sequential iteration is phased-task doesn't meet the design requirements or due to other tasks rework or a change in the task, resulting in completely tasks redone.

- **Sequence rework probability matrix (SRPM):** SRPk (i, j) represents the resulting probability of rework "i" in the No.k rework process when tasks "j" completed (i, j = 1, 2,..., n). i<j, it means that the next task unit "j" did not meet the design yet causing the forward task unit to rework which is called feedback rework; i>j, it means that change of task unit "i" caused next task unit "j" to rework which is called secondary rework. While iterations can reduce product quality but also increase schedule and cost, unlimited iteration is not proper, so it is necessary to make restrictions iteration:

$$SRP_{k+1}(i, j) = \begin{cases} m \times SRP_k(i, j) & SRP_k(i, j) \geq SRP_0 \\ 0 & SRP_k(i, j) < SRP_0 \end{cases}$$

SPR_0 is critical value in sequence rework, m is the probability of each iteration rework reduction coefficient (0<m<1). $SRP_K=SRP_0$ represents decrease of rework probability after each iteration; $SRP_K<SRP_0$, rework probability is small because of iteration, iteration should be terminated for continue to improving the quality of iteration comes with a price greater than the pay schedule and cost.

- **Sequence rework impact matrix (SRIM):** Sequence rework impact matrix element SRI (i, j) represents the rework time and workload of task unit "i" caused by unit "j" task accounted for the proportion of the original plan, this study argues SRI (i, j) approximately stays the same
- Learning curve S_i. Si^K represents the time and workload ratio of task unit "i" in the No.k. trial accounted for last time (i, k = 1, 2,...n). Learning curve shows that, with the increased number of iterations, the task rework time and cost showed a decreasing trend until the minimum
- Order actual cost (OAC) = $C_i+C_i\times$SRI (i, j) $\times S_i$ (i, j)
- Order actual cost time (OACT) = T_i+ $T_i\times$SRI (i, j)$\times S_i$ (i, j)

Consider resource conflicts of rework processing priority principle: In previous researches for WBS are aim to improve the quality of target units (Browning and Yassine 2011), largely ignoring resource-constrained impact project cycle and cost. However, there is competition for resources due to resource-constrained circumstances when multiple tasks performed in parallel or overlapping may occur. So considering these factors will make the work of the division of tasks decomposition unit implemented more efficient in the actual production process.

This study designs precedence rules are used to determine the allocation of resources and the conflict task units execution order. According to the resource constraints and resource allocation priority rules determine execution order rework tasks, adjust the project cycle. The higher the priority tasks of the feedback activities caused more demand for a resource is higher, such a task unit takes precedence.

$$Rpw_i = d_i + \sum_j d_j$$

where, Rpw_i allocation of resources for the task "i" priority; d_i denoted as the task completion time; d_j denoted as the expected completion time of subsequent task "i".

SIMULATION PRINCIPLE OF COMPLEX PRODUCT WBS PROCESS

Traditional Design Structure Matrix (DSM) is considered that till a task unit completely finished that information could be passed from one work to another (Agarwal *et al*., 2011). In fact, the downstream task don't necessarily need to wait until the end of previous task completed.

Combined with Multi-layer DSM thought, this study presents the DSM simulation model of WBS process which consists of two layers including main-layers DSM and sub-layers DSM. The main layer DSM is denoted as MDSM while the task node denoted as Ti (1, 2 ..., n) and it includes two kinds of the meaning: One is no overlap of work units; one is a overlapped task units which identified as the sub-layer DSM and it denoted as SDSM i (i = 1, 2,... n), the task node denoted as C_{ij} (i, j =1, 2,... n). The method of combined hierarchical and relationships: "1" element in MDSM represents no rework task units; non-"1" element represents a rework task units, non-"1" element including: variable identifier of the sub-layers DSM with a overlapped rework and the common tasks with rework but no overlapped rework.

In this study, the task completion time is the trigger point of the execution time, start and end of a task unit. Each simulation is started from the initial state of the system and randomly generates time and cost for each task unit according to its distribution. The main layer DSM model is run in the main program, excluding overlapping situations; the sub layer DSM model is run in the subprogram, taking overlapping rework and sequencing rework into account.

To obtain a stable distribution, a lot of simulations need to be run. The simulation runs is ended until the mean and variance is stable to certain accuracy á and it is checked by the following equation:

$$\frac{\left| E[T_r] - E[T_{r-b}] \right|}{E[T_{r-b}]} < \alpha, \qquad \frac{\left| \sigma^2_{T_r} - \sigma^2_{T_{r-b}} \right|}{\sigma^2_{T_{r-b}}} < \alpha$$

"r" is the number of runs and use $\alpha = 0.0001$, b=100 as the default here.

A CASE STUDY AND IMPLICATIONS

The simulation platform of WBS process is developed based on Matlab. Take a large ship enterprise as the research object to illuminate the validity and practicability of the simulation platform.The distributions of time and cost in task units are used the triangular probability density function to describe (Kim, 2007). Where t_m as the most optimistic completion time; t_p as the most likely completion time;t_0 as the most pessimistic completion time, cost model parameters use a similar method to describe. Using the Monte Carlo can extract duration and cost of each activity to generate the initial simulation data. The critical procedures and its initial data of cost and time are as shown in Table 1, two-layer DSM data are as shown in Fig. 1, relevant data for the sub-layers DSM are as shown in Fig. 2-4.

Table 1: Initial data of WBS process

	Time/day			Cost/millions		
Process	t_m	t_p	t_0	c_m	c_p	c_0
scheme demonstration T1	8	9	12	4.3	4.5	6.8
initiatory design configuration T2	19	20	35	2.7	2.8	4.9
prepare interior design drawingsT3	10	12	16	1.5	1.8	2.3
CFD analysisT4	36	40	49	3.5	4.0	5.0
set up primary structure T5	52	60	100	64.0	67.5	7.2
develop structure parameter T6	36	40	44	5.0	5.5	6.0
analyze inertiaT7	28	32	40	5.5	6.0	7.5
analyze stability controlT8	19	20	35	4.5	5.0	8.0
design FBD T9	72	80	88	10.0	11.0	12.4
analyze internal loadsT10	38	40	70	10.5	11.2	20.0
analyze structural stiffness and reliability T11	52	60	76	20.5	22.5	28.2
analyze MARP T12	120	130	144	71.0	76.0	78.0
analyze general layoutT13	54	60	72	10.0	12.2	14.0

	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13
T1													
T2	0.2												
T3		0.9			1								
T4		SDSM1	0.2					0.5					
T5		0.5	0.7										
T6		0.9	SDSM2	0.3	0.5								
T7		0.4			0.1				0.4				
T8	1			1									
T9				1			0.2						
T10				0.2		1	0.8	SDSM3	0.7				
T11					0.6			0.2					
T12		0.8				1							
T13	1		1	1		1			0.6				

Fig. 1: WBS in Shipbuilding process DSM

	C_{11}	C_{12}	C_{13}	C_{14}
C_{11}	1	0.7		
C_{12}	0.6	1	0.6	
C_{13}		0.8	1	0.7
C_{14}	0.5			1

(a)Rework Probability DSM

	C_{11}	C_{12}	C_{13}	C_{14}
C_{11}	1	0.1		
C_{12}	0.2	1	0.4	
C_{13}		0.2	1	0.3
C_{14}	0.3			1

(b)Rework Impact DSM

	C_{11}	C_{12}	C_{13}	C_{14}
C_{11}	1	0.2		
C_{12}	0.8	1	0.8	
C_{13}		0.4	1	0.7
C_{14}	0.5			1

(c)Rework Probability adjusting DSM

C_{11}	0.6
C_{12}	0.4
C_{13}	0.8
C_{14}	0.5

(d)Learning Curve

Fig. 2: Relevant data for $SDSM_1$

	C_{21}	C_{22}
C_{21}	1	0.2
C_{22}	0.8	1

(a)Rework Probability DSM

	C_{21}	C_{22}
C_{21}	1	0.1
C_{22}	0.2	1

(b)Rework Impact DSM

	C_{21}	C_{22}
C_{21}	1	0.55
C_{22}	0.65	1

(c)Rework Probability adjusting DSM

C_{21}	0.5
C_{22}	0.8

(d)Learning Curve

Fig. 3: Relevant data for $SDSM_2$

The model is programmed and simulated, then probability density, cumulative probability density of key process performance (schedule and cost) are made sure through statistical analysis. As shown in Fig. 5-6. The distributions of probability density of cost and schedule are approximate triangular. The sample data of joint probability density of the cost and schedule focus on central area, as shown in Fig. 5; there is few data sample point at both ends of diagonal direction. Cumulative probability distribution trends centerline direction as banding and two sides are symmetrical as shown in Fig. 6. It is fit to make rational budget plan base on the probability distribution characteristics. The possibility density arrives at peak value when schedule remains within 420-440 days, cost remains within 54-58 millions in the meantime, in this sense that lowest cost and fastest project progress may happen. It is beneficial to forecast

	C_{21}	C_{22}
C_{21}	1	0.2
C_{22}	0.8	1

(a)Rework Probability DSM

	C_{21}	C_{22}
C_{21}	1	0.1
C_{22}	0.2	1

(b)Rework Impact DSM

	C_{21}	C_{22}
C_{21}	1	0.55
C_{22}	0.65	1

(c)Rework Probability adjusting DSM

C_{21}	0.5
C_{22}	0.8

(d)Learning Curve

Fig. 4: Relevant data for $SDSM_3$

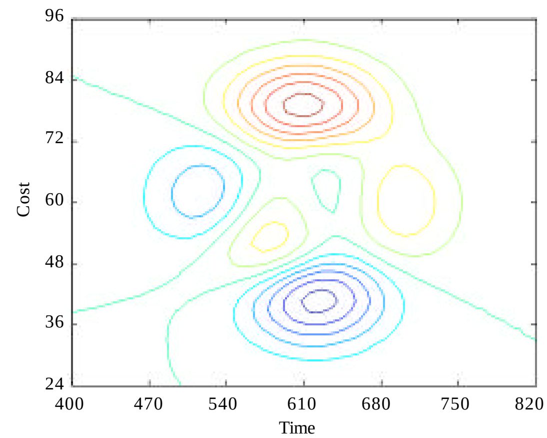

Fig. 5: Plan of joint probability density of Cost and Time

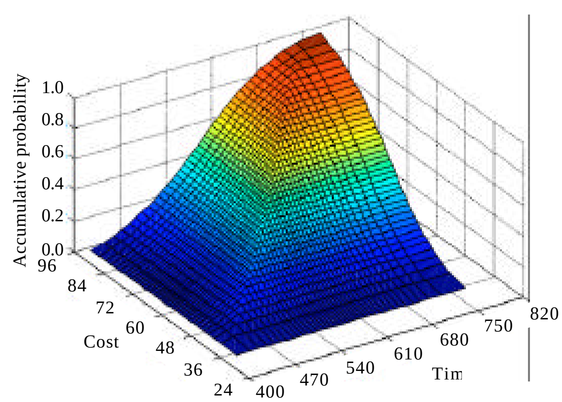

Fig. 6: Distribution of cumulation probability density of cost and time

and evaluate when made to work breakdown structure progress. The simulation value is approved by experiment result, process simulation is helpful to enhance the scientific rationality of project planning and budget, to improve the quality of project planning.

CONCLUSION

This study puts forwards two-layer DSM model aiming at the simulation forecast for work breakdown structure process of complex product project. Latin Hypercube Sampling is applied to schedule model and cost model which follow triangular distribution. and then presents DSM optimization method based on several kinds of rework tasks. The simulation models of some key problems are proposed, including overlapping iteration, sequential iteration and the rework judgment policy. A priority rule is designed to cope with resource conflict when existing uncertain factors and iteration; and a discrete event system simulation algorithm is developed, partly meant to improve the reliability of simulation algorithms. The example analysis shows that the simulation platform obey probability prediction, in order to increase the effectiveness of project management and planning which has certain practical value.

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