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An effective approach for scheduling coupled activities in development projects

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ABSTRACT

One of the greatest challenges in managing product development projects is identifying an appropriate sequence of many coupled activities. The current study presents an effective approach for determining the activity sequence with minimum total feedback time in a design structure matrix (DSM). First, a new formulation of the optimization problem is proposed, which allows us to obtain optimal solutions in a reasonable amount of time for problems up to 40 coupled activities. Second, two simple rules are proposed, which can be conveniently used by management to reduce the total feedback time. We also prove that if the sequence of activities in a subproblem is altered, then the change of total feedback time in the overall problem equals to the change in the subproblem. Because the optimization problem is NP-complete, we further develop a heuristic approach that is able to provide good solutions for large instances. To illustrate its application, we apply the presented approach to the design of balancing machines in an international firm. Finally, we perform a large number of random experiments to demonstrate that the presented approach outperforms existing state-of-art heuristics.

1. Introduction

Product development projects often comprise many coupled activities (Eppinger, Whitney, Smith, & Gebala, 1994; Shaja & Sudhakar, 2010). The sequence of these activities significantly affects the project completion time and cost. The design of a balancing machine (Fig. 1(a)), for example, comprises 70 activities. Among them, 31 activities are coupled, and their information dependencies are shown in Fig. 1(b), where nodes represent activities and arcs depict the information dependencies among them. Cyclic information flows are common among coupled activities. Moreover, precedence constraints among coupled activities are often unknown and subject to change (Ahmadi, Roemer, & Wang, 2001; Li & Chen, 2014). Because of the presence of information loops and uncertain precedence constraints, formal project scheduling techniques, such as program evaluation and review technique (PERT) and critical path method (CPM), are not applicable (Krishnan & Ulrich, 2001; Tripathy & Eppinger, 2011).

Some researchers (e.g., Bianco & Caramia, 2010, 2012; Chaney, Deckro, & Moore, 2013; Reyck & Herroelen, 1998; Schutt, Feydy, Stuckey, & Wallace, 2013) have relaxed the strict precedence assumption in CPM/PERT by introducing the generalized precedence relations (GPRs). GPRs specify a minimal or a maximal time lag between a pair of activities (Bianco & Caramia, 2012; Reyck & Herroelen, 1998; Weglarz, Jozefowska, Mika, & Waligora, 2011). Although the models with GPRs are useful for planning the timing and sequence of non-coupled activities, they cannot deal with cyclic information flows among coupled activities. Moreover, GPRs assume that the minimal or maximal time lag among activities are known and fixed, while in many situations, such precedence constraints among coupled activities are unknown and subject to change (Ahmadi et al. 2001). Another line of research develop the Graphical Evaluation and Review Technique (GERT), which allows for simulation-based analysis of activity networks with loops. GERT also permits for the calculation of duration distribution for some networks. However, calculating the duration distribution is very difficult even for a simple network. For a complex network, it has to resort to simulation to evaluate the project completion time (Banerjee, Carrillo, & Paul, 2007; Cho & Eppinger, 2005; Smith & Eppinger, 1997).

Recently, there has been a growing interest in applying the design structure matrix (DSM) for scheduling coupled activities (Karniel & Reich, 2009; Qian, Lin, Goh, & Xie, 2011). In a DSM, activities are listed on the left-hand side of the matrix as row headings and across the top row as column headings in the same order (Abdelsalam & Bao, 2006; Yassine, Joglekar, Braha, Eppinger, & Whitney, 2003). The sub-diagonal entries represent forward information transfer from upstream to downstream activities and the super-diagonal entries

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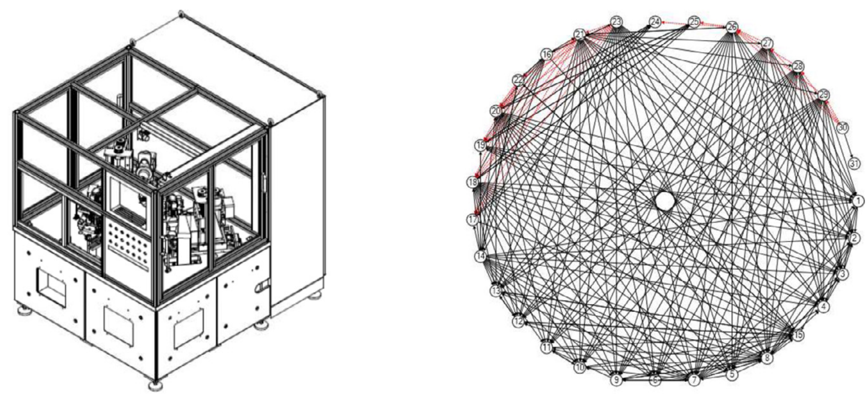

(**a**) Main components of the balancing machine (**b**) Graph representation of coupled activities

Fig. 1. Coupled activities in balancing machine design.

FEEDBACK

Activities		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Measuring the stiffness and nature frequency of the measure cartridge	1	4	0.3	0.2	0.1																											
Optimal design of the measurement-driven changeover components	2		3													0.1																
Design of the measurement-driven gripping components	3		0.2	4					0.2																							
Optimal designing measure speed control and indexing components	4		0.1	0.1	2																											
Rotating dynamic mechanical analysis	5					2		0.1	0.2																							
Simulation analysis motion and cycle time	6						2	0.1	0.2																							
Rotary drive component design	7	0.2	0.3	0.3	0.1			5	0.3	0.2	0.1	0.4	0.2	0.2		0.3																
Lift drive component design	8	0.1	0.1	0.2	0.3			0.2	5	0.4	0.3	0.2	0.1	0.2		0.2																
Load/unload interface component design	9							0.1	0.5	5		0.3				0.2																
Correction clamping component design	10										3	0.2				0.1																
Optimal component design of correcting indexing unit	11										0.1	2				0.1																
Design of correction slide's cost control system	12												4	0.3		0.4																
Component design of high intensity correction spindle	13												0.2	2		0.2																
Calculating the strength of the whole equipment	14	0.1	0.3	0.1	0.3	0.1	0.2	0.2	0.2	0.1	0.4	0.1	0.1	0.2	2			0.2	0.3	0.1	0.1		0.1									
Instrument's layout design	15												0.2	0.2		4		0.2	0.3	0.1	0.3		0.2									
Design of the electrical control cabinet	16														0.2	0.3	6	0.3	0.1	0.4	0.1	0.2	0.2	0.1								
Power circuit detail design	17																	3														
Control circuit detail design	18	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.3	0.2	0.1	0.1	0.3	0.3					4						0.3	0.1						
Design of the measuring system's data communication	19	0.1	0.2	0.1	0.1															3					0.2	0.2						
Review of the test electrical components and schematic design	20	0.1	0.1	0.4	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.2	0.1	0.2							3				0.2	0.4						
Designing I/O signals control	21	0.2	0.3	0.1	0.2	0.1	0.1	0.1	0.1	0.3	0.1	0.1	0.1	0.1				H	H	H	H	5					0.4	0.2	0.1	0.3		
Electrical wiring layout design	22														0.4	0.1	0.2	H	H	H	H	H	5									
Layout design of electrical components	23	0.2	0.2	0.3	0.1	0.1	0.1	0.3	0.1	0.1	0.1	0.2	0.2	0.1	0.1	0.1	0.3	H	H	H	H	H	H	5								
Basic process coding	24																	0.1	0.2	0.3	0.1				7							
Programming the module classification and module calling	25																	0.1	0.1	0.1	0.2					3						
Coding the control program for electrical input and output signals	26	0.1	0.2	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.1	0.1								0.2			H	H	5					
Coding the program for basic actions	27	0.1	0.4	0.2	0.1	0.1	0.2	0.4	0.5	0.2	0.1	0.1	0.2	0.1													H	3				
Coding the program for action interlock and error prevention	28	0.1	0.2	0.1	0.1	0.3	0.1	0.5	0.1	0.1	0.2	0.2	0.1	0.3													H		1			
Coding the program for cycle time statistics	29	0.2	0.2	0.1	0.2	0.1	0.3	0.1	0.3	0.2	0.4	0.2	0.1	0.1													H			1		
Software test	30																										H	H	H	H	15	0.2
Testing Equipment's mechanical position	31																															5

Fig. 2. DSM representation of coupled activities in balancing machine design.

denote feedbacks from downstream to upstream activities which may force a reworking of upstream activities (Eppinger, 2001; Qian et al., 2011; Steward, 1981). For example, the coupled activities and their information dependencies in balancing machine development is clearly depicted by the DSM shown in Fig. 2, where the diagonal numbers indicate the regular duration of activities, an “H” mark in row j and column i denotes a hard dependency, i.e., activity i must precede activity j, an off-diagonal number in row j and column i indicates the degree of information dependencies among activities, i.e., the percentage of activity j reworked after the completion of activity i.

The advantage of DSM over GERT lies in its tractability. It can provide a concise and clear representation of the information dependencies among coupled activities (Browning, 2001; Karniel & Reich, 2009). It is also easy and straightforward to evaluate the change of activity sequences. Therefore, since its introduction, DSM has gained increasing attention in scheduling coupled activities. In practice, DSM has been used for scheduling development activities at dozens of companies, including Boeing, General Motors, Intel, Rocketdyne, and so on (Ahmadi et al., 2001; Eppinger & Browning, 2012).

A number of models have been developed for scheduling coupled activities in DSM. A common practice is to find a sequence of coupled activities that minimizes the total feedback time (e.g., the total feedback time for the DSM shown in Fig. 2 is 54 days). We refer to such problems as feedback minimization scheduling problems (FMSP). The total feedback time, which is equivalent to the total amount of first-order rework, is a major driver for lengthy and costly product development (Ahmadi et al., 2001; Browning & Eppinger, 2002). Thus, it is accepted that in most cases, finding a sequence of coupled activities with minimum total feedback time can greatly reduces project completion time and costs. For example, Ahmadi et al. (2001) reported that the reordered activity sequence with smaller total feedback time has resulted in significant improvements in both project completion time and costs of the turbopump development at Rocketdyne. Similar