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Product development network modelling extensions to the cycle elimination method

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ABSTRACT

This paper considers Product Development (PD) project networks, which are characterized by stochastic activity durations and activity rework or iteration (i.e., potential to repeat some activities several times during PD execution). The Cycle Elimination (CE) approach presented in Nasr et al. (2016) reduces the computational complexity of analyzing iterative PD project networks by considering an approximate network with no iteration. We build on the CE approach to investigate practical scenarios which arise in real world PD projects which are not accounted for by the CE approach. These scenarios include: (i) forward probabilities, (ii) dynamic rework probabilities and proportions, (iii) multiple dependency relationships between activities, and (iv) different rework through indirect connections. We demonstrate these extensions using two case studies. The first case study considers a software development process, where we collected the data by interviewing the managers of the company. The second case study involves a hardware development process (adapted from Pinkett (1998)), where the results show that the proposed method outperformed three existing techniques from the literature. Both cases were solved using the proposed modification to the CE approach, and then simulated to gauge the accuracy of the proposed method showing very promising results.

1. Introduction

Product development (PD) projects are notorious for their iterative nature, where ignoring rework potential results in inaccurate estimates of project duration (and cost) and can lead to misleading analysis and managerial decisions (Browning & Yassine, 2016; Meier, Browning, Yassine, & Walter, 2015). Iterative rework is denoted by a feedback loop in an Activity on Node (AON) representation of the PD project network, where the completion of a downstream activity may cause one or more upstream activity to be reworked (Yassine & Braha, 2003). The stochastic nature of the activity duration along with the probabilistic occurrence of feedback loops, significantly increases the complexity of estimating the duration of the PD project (Browning & Ramasesh, 2007; Unger & Eppinger, 2009). Feedbacks are a typical characteristic of any complex design and development project and a potential source of design iterations, which can account for one-third to two-thirds of the project duration and cost (Meier, Yassine, & Browning, 2007). This fact makes the study of project management in the presence of iteration, as suggested in this paper, a central issue for the PD community.

In the absence of stochastic feedback, the PD network reduces to a classical project network where traditional and well-established techniques can be utilized such as the critical path method (CPM) and program evaluation and review technique (PERT) (Mantel, Meredith, Shafer, & Sutton, 2007; Pinto, 2012). When considering project networks which exhibit feedback, the majority of the literature utilizes simulation techniques (e.g., Abdelsalam & Bao, 2006; Browning & Eppinger, 2002; Cho & Eppinger, 2005) or heuristic algorithms (e.g., Browning & Yassine, 2016; Jun, Park, & Suh, 2006) to estimate the duration of the project. Analytical approaches to approximate the expected duration of PD projects exist but not without limitations; for example, the Reward Markov Chain (RMC) approach (Smith & Eppinger, 1997) and the Signal Flow Graph (SFG) approach (Eppinger, Nukala, & Whitney, 1997) are both used for sequential PD networks. More recently, the Cycle Elimination (CE) approach (Nasr, Yassine, and Abou Kasm (2016)) investigated the duration of a PD network for sequential and parallel networks. The CE method uses the RMC approach as a starting point and is extended to include finding the expected duration and variance of sequential, parallel, and mixed (i.e., combination of sequential and parallel activities) activity networks. The CE method mainly works by transforming the PD network into a traditional network (i.e. eliminating feedback) and then traditional project management techniques such as CPM and PERT can be used to calculate the

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expected duration and variance of the network.

Pinkett (1998) also implemented modifications to previous analytical methods, namely the signal flow graph (SFG) and the RMC. The modifications include rework proportions (i.e. repeating a fraction of the original activity duration when feedback is triggered). Another modification is accounting for "terminal probabilities". The terminal probability as explained by Pinkett (1998) is the probability that a certain activity will have to be reworked after the downstream activity, responsible for triggering the rework, is worked a second time (or more). Also, a modification to account for forward probabilities (p_f), the probability to skip an activity in the first iteration, is discussed. The terminal probability (identified as dynamic probability in our work) and the forward probability modifications in the case study presented by Pinkett (1998) inspired us to investigate further real case scenarios through a real world case study of our own accompanied by discussions with managers of a product development company. Pinkett's modifications along with different real case complications that were discovered are presented and discussed in this paper.

After reflecting on the different real case PD scenarios, we noted that additional complications can create limitations or inaccuracies in the original CE approach, if the method is used without some modification. Thus, this paper is dedicated to extending the CE method in order to account for these different complications or special cases. The issues that are addressed in this paper are:

(i) *Forward probabilities* that exist when there is a chance to skip a certain activity from the first iteration. For example, consider an employee receiving outsourced material which needs to be inspected for paint scratches before being sent to the assembly department to become part of a final product. Thus, the employee, in this case, can either send the material to the painting department or skip this activity and send it directly to the assembly department if found acceptable during inspection.

(ii) *Dynamic rework probabilities and proportions* that exist when the rework probabilities and proportions change with successive iterations (generally decrease) and this can be justifiable due to learning. For example, consider an engineer submitting a design for her manager's review. Assume that the first review, having an occurrence probability of 70%, requires the engineer to fix certain aspects of the design requiring 60% of the time spent on the original design. After the latter fixes as requested by the manager, the probability to ask for successive modifications decreases along with the duration to fix them due to a better understanding of what is required.

(iii) *Multiple dependency relationships between activities* that exist when a certain activity triggers more than one type of rework from another activity. This is best explained by a manager asking a subordinate to repeat a certain design where the amount of rework depends on amount of errors the manager detected; that is, the rework can target minor adjustments or detailed adjustments which require much more time.

(iv) *Different rework through indirect connections* that exist when two or more activities have the potential to cause rework for the same activity but each requesting a different kind of rework, then when the reworked activity triggers rework for another activity, the latter rework will depend on the kind of rework initially requested. For example, consider two engineers that design a product sequentially. The first engineer is in charge of preliminary design (A), while the second engineer performs detailed design (B). Now, consider two quality assurance employees, where one is responsible for technical inspections (C) and the other for visual ones (D). Each can provide feedback for activity (A) and then (A) feeds information to (B). The rework required from (B) differs depending on the initial feedback; that is, whether it is initiated from (C) or from (D) to (A). Note that there is no direct connection between (C) or (D) and (B).

This paper is divided into five sections. Following this section, a literature review is provided in Section 2. Then, the extensions and modifications of the CE method are discussed in Section 3 with illustrative examples. In Section 4, two real case studies are presented. The first, from a software development company, is presented highlighting the different complications. The second, adopted from Pinkett (1998), is presented where we compare our approximations with Monte Carlo simulation results as well as the results obtained in Pinkett (1998). Finally, summary, discussion and conclusion are presented in Section 5.

2. Literature review

Different literature streams such as, Browning and Eppinger (2002), Cho and Eppinger (2005), and Abdelsalam and Bao (2006) discussed simulation techniques to find the expected duration of a PD project network. However, due to the time-consuming nature of simulation techniques, our interest in this paper is developing or extending existing analytical techniques to solve a wider range of project networks. Specifically, the paper aims for extending the Cycle Elimination (CE) method developed by Nasr et al. (2016). Thus, the literature of the CE method fundamentals is first presented before moving to the details of the proposed extensions.

The Signal Flow Graph (Eppinger et al., 1997) and the Reward Markov Chain (Smith & Eppinger, 1997) are two analytical techniques used to calculate the mean and variance of the PD network durations. However, they suffer from limitations such as tackling only sequential PD projects and not including rework proportions (Nasr et al., 2016). A signal flow network represents the activities by nodes, while the arcs leaving the nodes represent the different mutually exclusive choices after an activity is worked, meaning that each activity can have at most one predecessor and thus parallel work is not allowed. This assumption can be relaxed by adding additional states that represent activities in parallel. Finally, a sequence of activities, called a path is defined for the network and rework is considered by allowing an activity to appear more than once. On the other hand, the RMC approach uses a modified form of Gaussian elimination to calculate the expected duration of deterministic activity sequential networks with feedback (Nasr et al., 2016). A stage in the method is defined by the completion of an activity along with all feedback generated by the same activity. The RMC works in a regressive manner, it starts with the duration calculation of the final stage and works itself backwards until the first stage duration is calculated and then sums all durations. The two methods, signal flow graph and RMC converge to give the same expected duration (Pinkett, 1998), where the signal flow graph calculates the expected duration to pass through the network while the RMC calculates the expected duration spent in the network.

Nasr et al. (2016) extended the RMC to account for rework proportions in the expected duration calculations as well as finding the variance in sequential activity networks. Moreover, they extended the method to account for parallel and coupled activities. As such, their method, called the cycle elimination (CE) method, requires the following as inputs: Rework probabilities & proportions, distributions of the activity durations, and the sequence of working the activities (with identifying sequential, parallel, or coupled activities). When it comes to sequential networks, the CE method's algorithms and formulations are used to find the expected durations at every stage and then they are simply summed. However, a bigger role is played in mixed networks. The cycle elimination approach starts by modifying the project network to allow for removing the feedback and then analyzing the network using traditional project management techniques. Specifically, consider the probability DSM (Design Structure Matrix) in Fig. 1 and its network representation in Fig. 2. The probability DSM in Fig. 1 shows the activity durations (in the diagonal entries) and the activity connections by the presence of any value greater than zero in the off-diagonal entries, where these values are the associated probabilities. For example, there is a 31% chance that Activity 4 will cause rework to Activity 2. Note