THE MECHANISM OF DESIGN ACTIVITY OVERLAPPING IN CONSTRUCTION PROJECTS AND THE TIME-COST TRADEOFF FUNCTION

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ABSTRACT

An effective and well known technique for earlier completion of construction projects is to overlap the project activities or phases that normally would be performed in sequence. Overlapping, also called fast-tracking, is inherently risky because it increases uncertainties and can result in more changes and rework. In order to gain maximum advantages from early project completion, a tradeoff between benefits and losses of activity overlapping is required. Such a tradeoff is a type of time-cost tradeoff. Various time-cost tradeoffs have been extensively studied in the project management and construction management literature; however, limited research exists to address the activity overlapping time-cost tradeoff. In this research, the theoretical mechanism of overlapping has been identified through a literature review and interviews with planning and scheduling experts. Then, an objective function that reflects the overlapping time-cost tradeoff is developed. The paper explains the overlapping mechanism in detail, and introduces the suggested objective function. It also shows that the most important negative impact of overlapping design activities is the rework occurring due to incomplete information exchange between activities; such rework has both time and cost impacts on overlapping and should be considered a key parameter in the time-cost tradeoff. The results of this research can generate insights for further research to solve the overlapping time-cost tradeoff and determine the optimum overlapping degree between activities in construction projects.

Keywords: Fast-tracking, overlapping, time-cost tradeoff, rework, construction management.

1. INTRODUCTION

The demand for project completion in a shorter duration has led to various methods of schedule compression. The Project Management Body of Knowledge (PMBOK) identifies fast-tracking as a schedule compression technique. In fast-tracking, phases or activities that normally would be done in sequence are performed in parallel; in other words they are overlapped. Overlapping can result in rework and increased risk. This approach can require work to be performed without complete detailed information; it results in trading cost for time, and increases the risk of achieving the shortened project schedule (PMBOK 2008).

In the literature, researchers have used other terminologies for overlapping, such as concurrent engineering, parallel engineering, phased construction, fast-tracking, flash-tracking, and agile project management. The available literature about overlapping can be classified into two main areas: product development and project execution. Since the manufacturing industry (automotives, electronics, etc.) utilized concurrent engineering long ago, the research for overlapping in product development is older and more extensive than that for project execution, particularly construction projects. Several researchers have investigated the inherent nature of overlapping and uncertainty resolution between activities in product development (Krishnan et al. 1996, Loch and Terwiesch 1998, Carrascosa et al. 1998, Prasad 1996). Roemer et al. have tried to determine the optimal overlapping policies (Roemer et al. 2000, Roemer and Ahmadi 2004). Some of the researchers such as Pena-Mora and Li (2001) and Bogus et al. (2005) have used the models and frameworks developed in product development research studies to develop similar models and frameworks in construction industry.

The objective of this paper is to provide insight into the overlapping mechanism. The available literature about overlapping has been reviewed to identify the mechanisms suggested by other researchers, and consequently semi-structured interviews were used to gather expert opinions, from mainly planners and schedulers, about the mechanism of overlapping. Accordingly, a mechanism is suggested which is explained in this paper.

2. OVERLAPPING PRINCIPLE

To better understand the overlapping principle, the type of relationships between activities should be identified. Bogus et al. (2005) have briefly explained Prasad's (1996) classification of relationship between design activities. According to them, four types of relationships between design activities are possible (Figure 1):

1) Dependent activities: In order to start, one activity requires the final information from another activity.

2) Semi-independent activities: To start, one activity requires only partial information from other activities.

3) Independent activities: No information dependency exists between two activities.

4) Interdependent activities: A two-way information exchange between the activities occurs until they are complete.

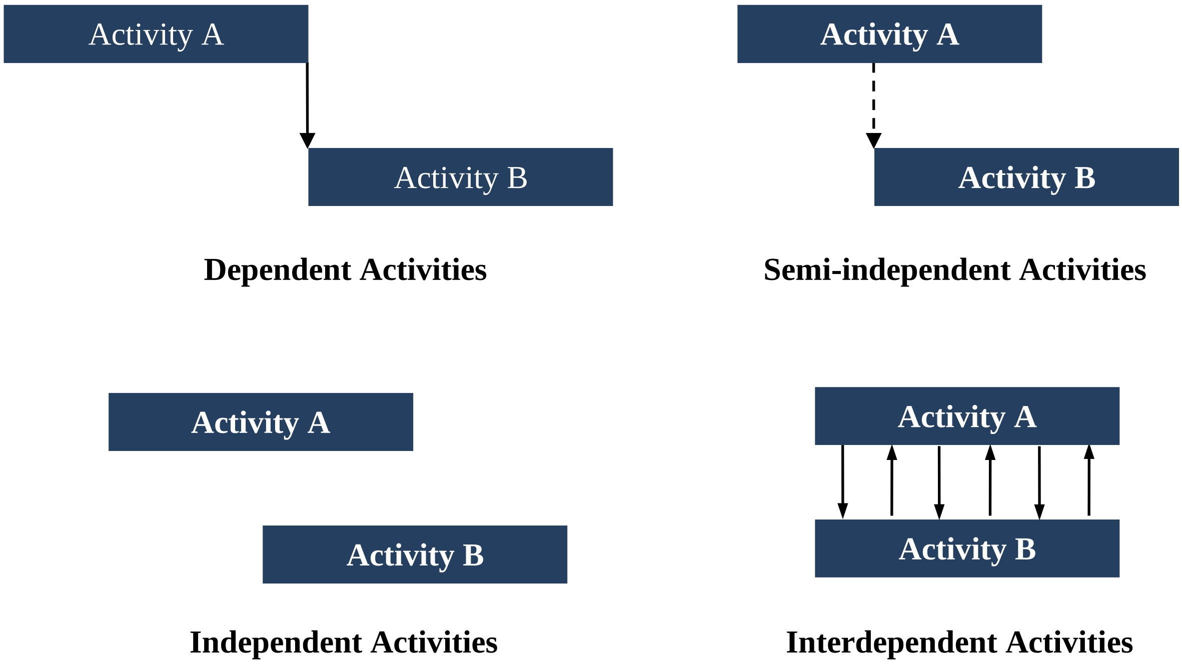

Figure 1: Four types of activity relationships (adopted from Prasad 1996; Bogus et al. 2005)

When it comes to activity overlapping, the above types of relationships vary remarkably in terms of risk. Overlapping *dependent* activities is the riskiest. This type of relationship is also known as finish-to-start dependency, implying that the first activity (predecessor) should be finished before the start of second activity (successor). Otherwise, the start of the successor before the predecessor may generate rework as the successor must begin before complete information is available from the predecessor. *Independent* activities can be overlapped to any extent, without any risks. The only requirement is that both activities' resources such as human, machinery, or material be available all at the same time. Most of the activities in a typical project schedule are independent activities. *Semi-independent* activities have a specific degree of overlapping by nature. However, more overlapping will be risky, similar to dependent activities. Finally, *interdependent* activities must overlap to exchange information and make progress, otherwise they cannot proceed. In other words, overlapping is a part of their inherent nature rather than a mean to save time. Although their overlapping is associated with risks of delay and rework, overlapping should not be considered an extra risk, but a must for interdependent activities. Based on the above, no specific overlapping risk exists when independent or interdependent design activities are overlapped. Risks are significant when overlapping dependent or semi-independent design activities.

Figure 2 shows the mechanism of overlapping two dependent activities, in which the start of an *activity* depends on the finish of another *activity* and the second activity can only be started if the first activity is finished completely. This is because the successor needs the information generated by the predecessor. However, to compress the schedule, the successor activity may be intentionally started before the completion of its predecessor. This becomes possible if the predecessor activity releases some preliminary information before its completion to the successor activity. Therefore, the successor can start sooner, using the preliminary information and making the necessary assumptions and predictions. The two activities can proceed in parallel for a while and, during this period, some intermediate information may also be transferred until the predecessor is completed; then, the predecessor will release its final information to the successor. At this point, it is likely that the final information is different from the preliminary or intermediate information and therefore, changes and adjustments should be made to the successor to make it compatible with the final information. The changes and adjustments will take some additional work (rework) in form of extra person-hours (i.e. extra cost and time), which means an increase in the duration of the successor activity compared to its normal duration.

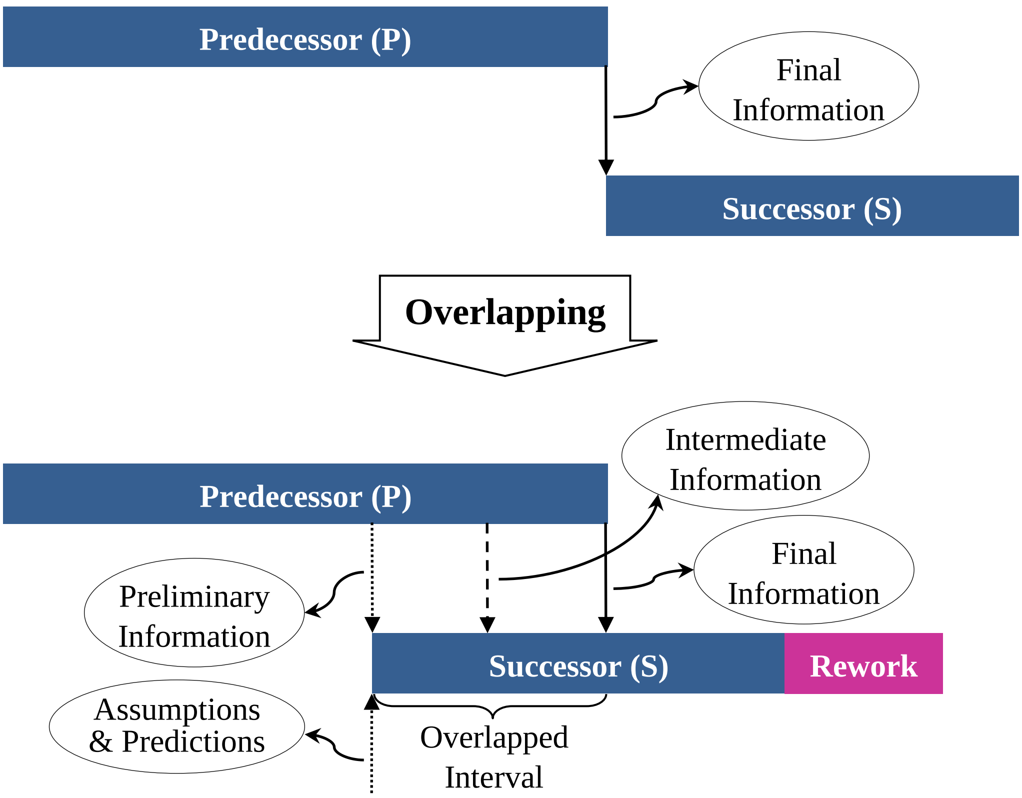

Figure 2: The mechanism of activity overlapping

It is noteworthy that the rework is not guaranteed to happen, i.e. no rework occurs if the final, preliminary, and intermediate information are compatible. So there is only a probability of rework that depends on several factors. In this research, the literature review shows and the interviews endorse that these factors are the type and complexity of overlapped activities, their relation with other activities in the project schedule, and the amount of overlapping. On the other hand, the amount (the duration) of additional work is a function of overlapping duration and the intensity of nonconformity between final and preliminary information. The maximum rework may happen when the final information is significantly contradictory with the preliminary information, and successor is required to apply a major change. In such a situation, the worst scenario is that the successor must disregard all its progress during overlapping and start over. Therefore, the rework amount, whatsoever, is not logically more than the overlapping duration.

The above mechanism of overlapping dependent activities can also be applied to semi-independent activities by considering the predecessor as two separate sequential activities (A1 and A2), one before (A1) and the other (A2) after the information exchange (Figure 3); Activity A1 becomes the predecessor for both activities A2 and B. Therefore, activity A1 and activity B may overlap with the same mechanism of dependent activities, and activity A2 and activity B can easily overlap because they are independent.

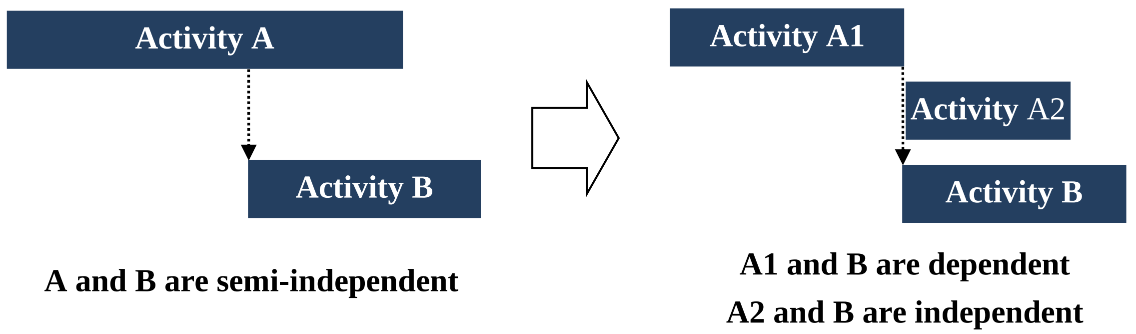

Figure 3: Semi-independent activities' overlapping

3. OVERLAPPING TIME IMPACT

By implementing the above overlapping mechanism in the project schedule, the real timesaving of design activity overlapping can be better identified (Figure 4). If two activities on the project critical path overlap, the actual time saving will not be equal to the overlapping period as it may first seem. Instead, the actual time saving equals the overlapping period minus the rework period. However, the survey performed in this research showed that in real world practice, schedulers do not consider the rework period during scheduling, causing their schedules to be a little unrealistic. In some companies though, risk analysts consider the risk of rework when they conduct schedule risk analysis.

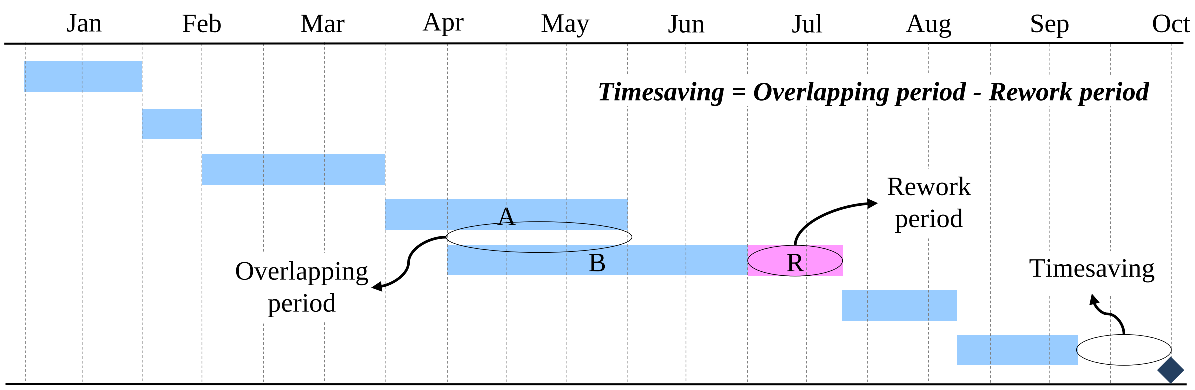

Figure 4: Overlapping time impact on the project schedule

4. OVERLAPPING COST IMPACT

The unique advantage of overlapping is the timesaving it generates in the project, which consequently results in a long list of benefits such as earlier operation, earlier income, time to market, increased market share, tax reductions, reduced payback period, increased prestige, etc. Such benefits have their roots in the business objectives of the project. The main problem lies in extra risks generated, with the risk of rework the greatest. Overlapping can result in more changes, which consequently can result in more rework; more rework can increase expenses and lengthen execution time of the project. Further, sometimes overlapping necessitates utilizing exceptional work procedures, which can adversely affect project quality requirements and even jeopardize safety. This means that too much overlapping cannot be applied, because only reasonable levels of risk can be tolerated. If too much overlapping is implemented, then the time saving benefits might be offset and even superseded by the losses originating from rework and cost. Therefore, a tradeoff is required between the overlapping timesaving benefits and its risks and costs (Dehghan et al. 2010). Then it is feasible to assess how much overlapping is desirable or which degree of overlapping is optimum.

5. OVERLAPPING TIME-COST TRADEOFF

The first step towards establishing the time-cost tradeoff is to convert risks of overlapping into equivalent costs. A probability and a cost impact are allocated to each degree of overlapping between each pair of activities. The probability value determines the likelihood that rework happens as a result of overlapping. The cost impact value represents the cost effect of rework, if it happens, and consists of two parts. The first part is the total daily rate of successor activity, which includes daily salaries and daily overheads. The second part is related to any other costs (other than the daily rate of successor activity). An example is the cost of changes and rework in the subsequent engineering, procurement and construction activities (Equation 1).

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$$\text{Overlapping cost} = P_{ijk}\,(T_{ijk}\,R_j + C_{ijk}) \qquad (1)$$

i Index denoting predecessor activities

j Index denoting successor activities

k Index denoting degrees of overlapping (overlapping intervals) between predecessor activity i and successor activity j

P_{ijk} Probability that rework happens for activity j because of its overlap k with activity i

T_{ijk} Added duration to successor activity j, as a result of rework originating from the changes made by predecessor activity i, during overlapped interval k

R_j Total daily rate of successor activity j, including daily salaries and daily overheads

C_{ijk} Extra costs, other than daily salaries and overheads, imposed on successor activity *j* because of the changes made by predecessor activity *i* during overlapping interval *k*

On the other hand, if an overlapping is on the project critical path, it will reduce the critical path duration and very likely the project duration. If an overlapping reduces the project duration, its benefit is attributed to the benefits of project early finish (Equation 2).

$$\text{Overlapping benefit} = C_{ef}\,(T_n - T_o) \tag{2}$$

C_{ef} Project daily early finish benefits

T_n Normal project duration before overlapping

T_o Total project duration after overlapping

The interviews in this research showed that C_{ef} , includes but is not limited to the following:

- Daily benefits resulting from saving indirect costs
- Daily incentive amounts for early completion according to the project contract
- Daily benefits of new opportunities obtainable because of early completion
- Daily benefits of gaining reputation for timely finishing the project

The tradeoff should be performed between equation 1 and equation 2. The objective is to minimize costs and maximize benefits of overlapping. In other words, the objective is to minimize *Z* in equation 3:

$$Z = P_{ijk}\,(T_{ijk} R_j + C_{ijk}) - C_{ef}\,(T_n - T_o) \tag{3}$$

Equation 3 can be considered as the objective function representing the overall cost-benefit impact of any overlapping in the project. Optimization techniques should be used to simultaneously optimize the above equation for all potential instances of overlapping in the project schedule.

6. CONCLUSIONS

The mechanism of overlapping for design and engineering activities in construction projects is different from that for other types of activities, such as procurement, construction, and commissioning. The main objective of this paper was to generate insights to better understand the mechanism of design activity overlapping. While background information in the paper can be found in other research, it is scattered. In this paper, the available knowledge has been consolidated and focused. Furthermore, the findings in the literature were questioned by interviewing construction experts such as project managers, planners and schedulers and some modifications were applied. The result is a detailed explanation of the inherent nature and mechanism of overlapping which is believed to be a realistic reflection of practice.

The paper also reviewed the time and cost impact of overlapping on the project schedule. Then an objective function showing the total cost of overlapping was formulated. This cost function can be formed for each overlapping in a project. To minimize costs and gain optimum overlapping, the cost functions should be minimized for all instances of overlapping in the project schedule. Therefore, the next step of this research will be to acquire and implement a suitable optimization technique for the purpose of minimizing the cost functions and optimizing activity overlapping.

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