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# SIMULATION-BASED APPROXIMATION OF THE GAIN FROM APPLYING OVERLAPPING ACTIVITIES

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## ABSTRACT

Schedule management is substantial in construction projects to ensure successful completion. However, the dynamic nature of the construction industry introduces variability, leading to uncertainty and challenges in schedule implementation. This paper explores the use of schedule acceleration through overlapping activities as a solution to mitigate the impact of variability on project timelines. Risks associated with overlapping activities can lead to waste and offset anticipated schedule gains. To challenge the assumption that the schedule gain from activity overlapping is directly proportional to the amount of overlapping, a simulation model is developed and implemented in MATLAB where activities are modeled as beta-distributions. The model gradually increases the overlap percentage and evaluates the mean best-case, overall mean, and mean worst-case durations. An isolated overlap consisting of two activities is used to demonstrate the effect of overlapping. With a 1:1 ratio between durations, it was found that, when using a 90% overlap, the loss in effect varied from 3.2% to 57.5 % with an overall mean loss of 34.2%. These results emphasize that even in the most optimistic combination of distributions, the most likely duration still exceeds initial expectations, indicating the influence of variability on the schedule. Thus, the findings highlight the necessity of project managers to consider the impact of variability on overlapping activities, ensuring a more accurate schedule estimation. The study offers practical recommendations for project managers including a diagram that advocates applying adjustment coefficients based on the degree of overlap and the ratio between the activity's durations. The diagram can be adopted in future scheduling to adjust durations when applying overlapping to minimize the risk of schedule delays.

## 1 INTRODUCTION

In the realm of construction projects, schedule management is essential to ensuring successful project completion. Traditionally, construction scheduling follows a linear and sequential approach, where each activity is planned and executed in a predetermined order. However, the dynamic nature of construction often presents challenges that demand flexibility and adaptability in scheduling practices. Variability, a key aspect of construction projects, introduces uncertainty and unpredictability, necessitating the exploration of innovative approaches to schedule management. The presence of variability, which manifests as variation, at both the trade contractor and project levels makes it difficult to effectively manage and control the impact on project timelines (Arashpour & Arashpour, 2015).

As a result, owners and contractors face challenges in completing construction projects on time, which often leads to disputes and litigation (Chang et al. 2019). Hence, they adopt schedule compression which is a common practice used to complete projects faster but can lead to productivity loss and increased costs. In recent years, schedule acceleration through overlapping activities has emerged as a potential solution to mitigate the impact of variability on project timelines. Activity overlapping involves strategically coordinating and executing tasks concurrently or partially overlapping, allowing for a more fluid and

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flexible construction schedule (Dehghan et al., 2010). This approach aims to compress project duration and mitigate delays caused by variability, ultimately enhancing project efficiency and reducing overall costs.

Although activity overlapping has been implemented in fast-tracking, large-scale, and complex construction projects (Srour et al., 2013), it is important to consider that substantial schedule overlapping can potentially have a detrimental effect on the performance of construction operations associated with these activities (Moon et al., 2015). Overlapping activities pose risks such as site overcrowding (Igwe et al., 2020), increased rework (Hazini et al., 2013), and frequent claims (Moazzami et al., 2011), which lead to waste. For instance, when there is site overcrowding due to overlapping activities, the efficient movement of resources and workers can be impeded, resulting in inefficiencies and potential delays. Similarly, increased rework caused by overlapping activities can lead to the need for additional time to rectify errors or fix incomplete work, offsetting any potential schedule gains. Moreover, frequent claims arising from overlapping activities can result in disputes, negotiation processes, or legal actions, further extending project duration.

Put simply, while activity overlapping may initially seem like an effective way to compress project duration, the practical outcomes may not align with the expected time savings. It is often assumed that the amount of schedule gain is directly proportional to the amount of overlapping. For instance, in deterministic scheduling, the durations are basically identified by summing the mean of each activity and the gain from overlapping is overestimated. However, due to activity interrelationship and variability, this assumption is very optimistic. There is a scarcity in research studies evaluating schedule gains achieved through activity overlapping. In a previous study, the authors looked at how activity overlapping leads to emerging waste in a schedule (Salhab et al., 2023). This study, however, takes a more general perspective and seeks to address the mentioned scarcity by challenging the current assumption and arguing that the schedule gain from activity overlapping is not the same as the amount of overlapping. A simulation model is developed and implemented in MATLAB-R2023a where the activities are modeled using beta-distributions. The model considers the effect of the distribution function while gradually increasing the overlap percentage from 0% to 90% and evaluating each time the best-case (BC), mean, and worst-case (WC) durations. In each simulation run, the model compares the changes in duration to the expected mean duration calculated using a classic deterministic approach. The model is tested by isolating one overlap consisting of two activities to zoom into the effect of overlapping. The study compares diverse carefully selected distribution functions to ensure that the findings can be generalized to any two overlapping activities in a schedule, and to identify and adjust for the expected loss in effect even when the probability distribution functions are unknown. In order to accommodate for the effect of overlapping, corrections to the expected loss have been identified and depictured in a diagram mapping the expected loss as a function of the degree of overlap and the ratio between durations of the two activities. The study therefore provides empirical evidence and theoretical analysis to support the argument and offer practical recommendations for project managers to adjust the schedule accordingly and minimize the risk of schedule delays.

# 2 LITERATURE REVIEW

The topics of overlapping and variability are interconnected, as they collectively explore different aspects of project scheduling and management. The studies on the impact of overlapping shed light on the consequences, risks, and benefits associated with overlapping activities within a project. This knowledge is then utilized in the pursuit of optimizing overlapping, where researchers propose models, algorithms, and frameworks to achieve the most effective and efficient use of overlapping techniques while considering project constraints and objectives. Additionally, the investigation into the impact of variability on duration examines how variations in activity durations or workflow affect project timelines and performance. By

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understanding the interplay between overlapping, optimization, and variability, researchers aim to enhance project planning and execution, minimize risks, and improve project outcomes.

Variability, especially evident in industries like construction, is marked by inconsistency. This irregularity negatively impacts production metrics, often leading to extended project durations due to factors like necessary rework (Arashpour & Arashpour, 2015). Such distinctions in variability are foundational in both project management and production domains. In many ways, understanding this is akin to recognizing that increased variability can decrease a system's production capacity, as posited by the law of manufacturing (Hopp and Spearman, 2000). In the context of projects Elmaghraby et al. (1999) highlighted the pivotal role of critical paths, indicating that project duration changes are closely tied to the number of activities on the most critical paths and their competing counterparts. Gutierrez and Paul (2001) shed light on an intriguing aspect, noting that smaller projects, counterintuitively, may not always be the most susceptible to increased activity variability. Instead, larger projects with parallel activities that exhibit minimal overlap might be more vulnerable. Madadi and Iranmanesh (2012) further simplified this by pointing out that merely around 20% of activities, as derived from the Pareto principle, truly impact project completion time. Hajdu and Bokor (2014) emphasized the paramount importance of the three-point estimation's accuracy over any specific activity distribution used in predicting project duration. On a more operational level, Arashpour and Arashpour (2015) identified rework as a major factor causing variability, leading to workflow disruptions and time wastage across sectors.

Overlapping can produce varied outcomes. William et al. (1998) state that the overlap degree doesn't necessarily affect the magnitude of project changes. However, Chang et al. (2019) found an undeniable correlation between schedule compression scenarios and reduced labor productivity. This inclination for schedule compression appears more pronounced in industrial projects, as identified by Webb et al. (2015), leading to augmented safety risks compared to other sectors. Biruk and Rzepecki (2021) brought the discussion back to efficiency, focusing on the sequencing of parallel processes, while Gunatilake and Theivendran (2015) stated that despite its merits, schedule compression necessitates judicious application.

The endeavor to streamline overlapping in projects has birthed several insightful contributions. Ballesteros-Pérez (2017) set a notable threshold, stating that project schedules resist compression beyond a quarter (25%) of their initial duration. Innovative strategies, like Gwak et al.'s (2016) model, offer valuable tools to swiftly identify global overlaps and ensure project constraints are met. This is complemented by Moon et al. (2015), who brought forth a novel algorithm focusing on schedule overlaps. Practical validations, such as the one presented by Hazini et al. (2013), underscore the potential of these strategies, showcasing a 16% reduction in project duration. However, Grèze et al. (2012) and Dehghan et al. (2010) point out the need of maintaining a balance. Overlapping can indeed trim project duration but may inadvertently increase associated costs and workload. Finding the ideal overlap degree is difficult, but heuristic methods that combine data-driven research with intuition may be effective in this attempt, as highlighted by Bogus et al. (2005). Wang and Lin (2009) and Biruk and Jaśkowski (2020) emphasize the strategic benefit of understanding activity overlap details to reduce project delay risks and identify the best course of action should delays occur. Table 1 summarizes and categorizes findings and contributions from major studies that pioneered schedule compression.

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**Table 1.** Summary of major findings in the literature.

| | Authors & Year | Key Findings / Contributions |
|---|---|---|
| Impact of Variability on Duration | Arashpour and Arashpour (2015) | Factors like rework causing variability can significantly increase completion times and result in workflow congestion and wasted time across trades. |
| | Hajdu and Bokor (2014) | The accuracy of the three-point estimation is more crucial in determining the project duration distribution than the specific activity distribution used. |
| | Madadi and Iranmanesh (2012) | Only a small proportion of activities (around 20%, based on the Pareto principle) significantly affect the project's completion time. |
| | Gutierrez and Paul (2001) | Contrary to intuition, smaller projects aren't always more affected by increased activity variability. If parallel activities have little overlap, larger projects might be more impacted. |
| | Elmaghraby et al. (1999) | The change in the duration of a project depends on whether an activity is on one of the most critical paths and how many paths compete with it. |
| General Impacts of Overlapping | Biruk & Rzepecki (2021) | Different processes can be carried out simultaneously, with efficiency influenced by whether or not they're being conducted alongside a preceding or succeeding process. |
| | Chang et al. (2019) | Using the logistic model, contractors and owners can ascertain the probability of a project being impacted by schedule compression. This knowledge aids in identifying responsibility and potential compensation discussions between owners and contractors. |
| | Gunatilake and Theivendran (2015) | Schedule compression, while useful, needs careful application and management. Without proper strategies in place, its implementation might lead to more problems than solutions in the construction industry. |
| | Webb et al. (2015) | Industrial projects more frequently use schedule compression techniques compared to residential and commercial projects, which leads to increased safety incidents. |
| | William et al. (1998) | The degree of overlap in a project doesn't generally influence the amount of project change. |
| Optimizing Overlapping | Biruk & Jaśkowski (2020) | The simulation experiment was able to pinpoint the optimal lag between the time a delay occurs and when duration compression measures should be implemented. In both cases studied, this lag was found to be two days. |
| | Ballesteros-Pérez (2017) | On average, schedules can't be compressed beyond 25% of the original project duration. |
| | Gwak et al. (2016) | The developed model aids in optimizing construction scheduling by pinpointing exact global overlaps between activities swiftly. It provides a framework that meets project constraints regarding budget and duration, facilitating comparisons under different project conditions. |
| | Moon et al. (2015) | A new algorithm that identifies schedule overlaps was developed and validated using a real-life case study. |
| | Hazini et al. (2013) | The presented method was tested on a case study, and results showed it saved 16% of the project duration and determined the best arrangement for accelerating and overlapping activities. |
| | Grèze et al. (2012) | Overlapping reduces the total project duration but may increase the workload and associated rework costs. |
| | Dehghan et al. (2010) | If the net benefit of overlapping is negative or zero, the overlap should be reduced. If positive, various overlapping degrees should be checked to find the one providing the highest net benefit.<br>Searching for the optimal overlap might be best performed using heuristic methods, which combine data-driven analysis with human intuition. |
| | Wang & Lin (2009) | By understanding the nuances of activity overlapping, project managers can strategically reduce the risk of project delays, ensuring timely product launches in the market. |
| | Bogus et al. (2005) | While overlapping dependent activities in a project can potentially reduce delivery time, it's a decision fraught with complexities, risks, and potential costs. Proper planning, backed by analytical solutions and comprehensive data, is crucial to make the best decisions in this regard. |

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Although the existing body of literature offers invaluable insights into project variability, overlapping, and the impacts of both, certain gaps remain in the authors’ understanding such as establishing quantitative analysis of overlap proportionality. The assumption that the gains from activity overlapping are directly proportional to the overlap's degree hasn't been rigorously tested. Hence, this study seeks to evaluate proportionality of schedule gains from overlapping. The study offers value, in part due to its use of computer simulation techniques. Through these simulations, researchers can better understand the complexities of construction projects by mimicking real-world scenarios in a digital setting. This method not only deepens our comprehension of the challenges but also presents opportunities to test potential solutions, marking it as an essential tool for progress in the construction domain.

# 3 METHODOLOGY

The purpose of this study is to address the lack of approaches that evaluate schedule gains achieved through applying activity overlapping, and Design Science Research (DSR) methodology is adopted to achieve this. DSR methodology focuses on developing innovative and effective solutions to practical problems by designing, implementing, and evaluating artifacts (Offermann et al., 2009). The methodology consists of three main phases: problem identification, solution design and development, and solution evaluation.

To build a solution for the identified problem, a simulation model is developed in MATLAB. Although there exits plenty of software to choose from, MATLAB was selected because it offered several key benefits that align with this research objectives such as computational flexibility and customization, statistical and numerical analysis, integration of complex algorithms, and graphical visualization. First, each activity was divided into sub-activities. Then, the simulation model designated durations to the main activity and each sub-activity using a stochastically assigned beta-distribution with a pre-defined probability density function (PDF). The choice of the beta-distribution was influenced by its recognized flexibility in simulating durations, a notion supported by various previous studies. Notably, the shape of this distribution was largely dependent on two parameters, namely the coefficient of variation ($v$) and skewness ($k$), as outlined by Johnson (1997). Embracing these characteristics, the study opted for a positive-skewed beta-distribution, mirroring real-world construction scenarios where some tasks may exceed anticipated time frames. The overlapping impact between the activities was observed by progressively increasing their overlap from 0% to a notable 90%.

The simulation model was then applied to an isolated overlap of two activities, "A" and "B", both with a 10-day duration (defined as 1 unit) to clearly demonstrate the gains and losses resulting from applying overlapping. The sub-activities were delineated for these primary activities, with clear inter-relationships. Durations for both the principal activities and their respective sub-activities were anchored in the beta-distribution and were aptly scaled to maintain consistency and relevance. Fig. 1 summarizes the adopted research methodology, and the following section details the model assumptions and development.

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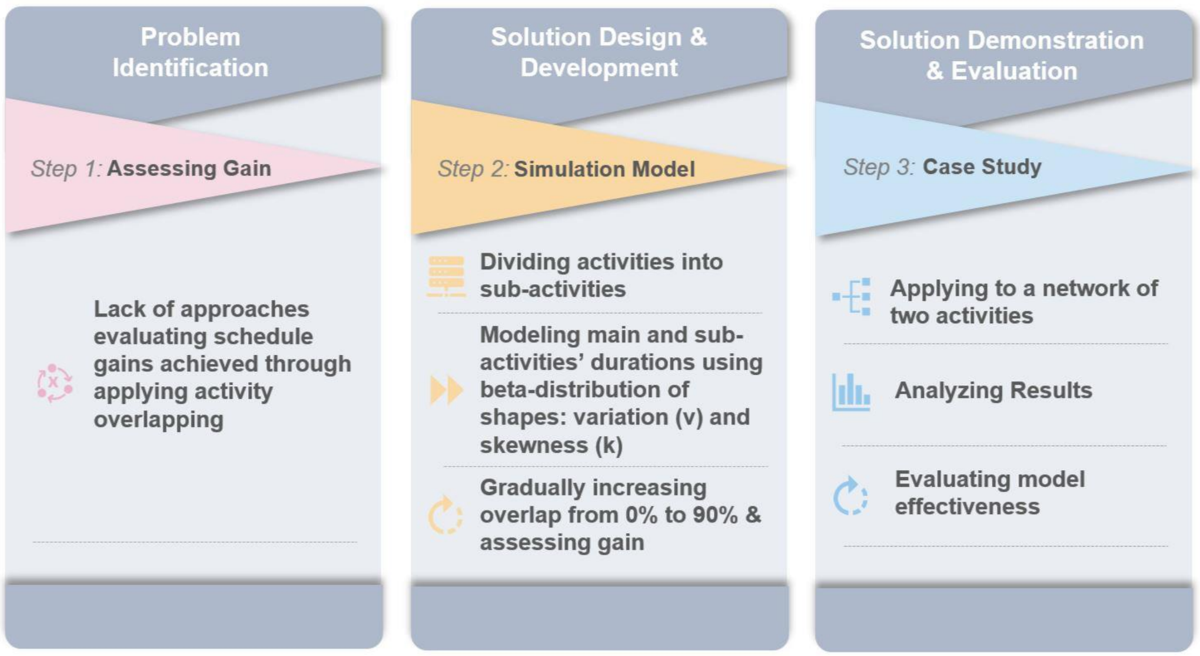


**Fig. 1.** The research methodology.

## 4 MODEL ASSUMPTIONS AND DEVELOPMENT

To estimate the gain from compressing the schedule by overlapping activities, MATLAB is applied to generate a stochastic simulation model consisting of a series of Monte-Carlo simulations. The simulation starts by assigning each sub-activity a unique stochastic duration sampled from a beta-distribution with a pre-defined PDF. The beta-distribution is characterized with flexibility (AbouRizk & Halpin, 1992) and thus, is selected as the dominant distribution for simulating durations (AbouRizk et al., 1994; Fente et al., 2000; Lindhard et al., 2019; Salhab et al., 2022; Schexnayder et al., 2005). Specifically, previous studies showed that an activity duration tends to follow a positive skewed beta-distribution (AbouRizk & Halpin, 1992; Fente et al., 2000). Since the actual shape of the beta-distribution varies and depends on the activity characteristics, all possible shapes of each activity's beta-distribution must be identified. Based on this, all possible combinations of the activities' identified beta-distributions are simulated to approximate the overall estimated project durations.

Generally, the shape of the beta-distribution is determined by specific parameters. In this study, the possible shapes of the beta-distributions are identified following the approach adopted by Johnson (1997) where the beta-distribution is generated using two variables which are the coefficient of variation ($v$) and the skewness ($k$). The PDF represented by $f(x)$ is established using Equation 1:

$$f(x) = \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)} x^{\alpha-1}(1-x)^{\beta-1}, 0 \leq x \leq 1, \alpha, \beta > 0 \qquad \text{Equation 1}$$

Where $\Gamma$ denotes the gamma function, $\alpha$ and $\beta$ denote the shape parameters of the distribution, and $x$ denotes the variable which is in this case the activity duration.

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As already mentioned, an activity duration tends to follow a positive skewed beta-distribution. Therefore, assuming that the beta-distribution is symmetric or positive skewed entails that both parameters should be greater than 1, and $\beta$ should be greater than or equal to $\alpha$ as shown in Equation 2.

$$\beta \geq \alpha > 1 \qquad \text{Equation 2}$$

The shape parameters $\alpha$ and $\beta$ are calculated based on $v$ and $k$ using Equation 3 and Equation 4 below.

$$\alpha = \frac{2(1 + kv - v^2)}{v(kv^2 + 4v - k)} \qquad \text{Equation 3}$$

$$\beta = \frac{\alpha v^2(\alpha + 1)}{1 - \alpha v^2} \qquad \text{Equation 4}$$

From the characteristics and parameter shapes of the general beta distribution, it can be shown that:

$$v - \frac{1}{v} < k < 2v, \text{ where } v > 0 \qquad \text{Equation 5}$$

Finally, by combining the expression of beta-distribution, the shape parameters, and the shape restriction (symmetric or positive skewed), $k$ can be calculated using the reduced form in Equation 6.

$$k \geq \frac{2(3v^2 - 1)}{v(3 - v^2)} \geq 0 \qquad \text{Equation 6}$$

To reach a general conclusion, the model combines 233 different PDFs that cover the entire allowable region of the $(v, k)$ plane. Finally, the ratio between the duration of the two activities is varied. The reason for choosing a right-tailed (positive skewed) beta-distribution is to limit the combinations within the more realistic range. The positive skewed distribution implies that some activities might take longer than expected which reflects the real-world construction. Also, it is assumed that deviations are due to schedule variation and that other factors such as congestion are not considered.

The following sections demonstrate the model application followed by analysis, discussion, and conclusion.

# 5 MODEL APPLICATION

A common scheduling practice which involves slab pouring and formwork installation in a building construction project is presented to further illustrate the alignment of the model assumptions with real-life construction scenarios. In a typical project schedule, it is common practice for construction teams to prioritize pouring an entire floor's slab before commencing formwork installation for the subsequent level. This approach ensures stability, safety, and efficient resource allocation, as well as conforming to the logical finish-to-start relationship between these sub-activities. However, in the context of an accelerated schedule, the project superintendent may resort to a strategic deviation from the traditional approach. Recognizing the need for time reduction, the superintendent might decide to initiate formwork installation for the next level after approximately half of the slab for the current level has been poured and cured sufficiently. This adjustment allows for an overlapping of activities. By introducing this adjustment, the superintendent acknowledges the need to revisit the finish-to-start assumption between these sub-activities. The decision to overlap these activities reflects a deliberate deviation from the conventional sequencing logic, which the suggested model captures by evaluating the effects of overlapping activities with varying degrees of overlap.

Now to demonstrate the effect of overlapping in a more generic way, an isolated overlap was simulated consisting of two activities “A” and “B”, each with a length of 1 unit where 1 unit is equal to 10 days. First, the simulation only considers the effects of interrelationships between the activities; thus, the durations of activity A and B are assumed to be independent with regards to effects of congestion (shared spaces and

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resources) and added complexity. In other words, even though activities A and B have interrelationships (meaning they might influence each other), their durations are treated as if they are independent in the context of the study. Second, the activities are assumed to have a finish-to-start relationship, i.e., activity A must be completed first for activity B to start. Thus, when conducted in series, the activities have a total duration of 2 units. Afterwards, the overlap between the two activities is gradually increased by 10% from 0% to 90%, resulting in 10 different simulations. This corresponds to two activities, each with a duration of 10 days where the overlap between them is increased from 0 to 9 days. Activities A and B are then divided into 10 sub-activities each representing one tenth of the work as depicted in Fig. 2. The relationships between the sub-activities are then encoded.

Each sub-activity's duration is modeled after the duration behavior of its parent activity. This modeling uses consistent $\alpha$ and $\beta$ parameters. To ensure consistency, the combined durations of all sub-activities must equal the duration of the main activity. Both the main activity and its sub-activities have their durations set using the beta-distribution, which initially produces values between 0 and 1. These values are then scaled, meaning the main activity's duration scales to a single unit, while the sub-activities' durations are adjusted to match the main activity's total time. In addition, any finish-to-start relationships between sub-activities are factored into final duration adjustments. Importantly, a specific rule is applied during these calculations: a sub-activity from one main task (say, B) cannot outpace its counterpart in another task (say, A) if A and B have a start-to-finish relationship.

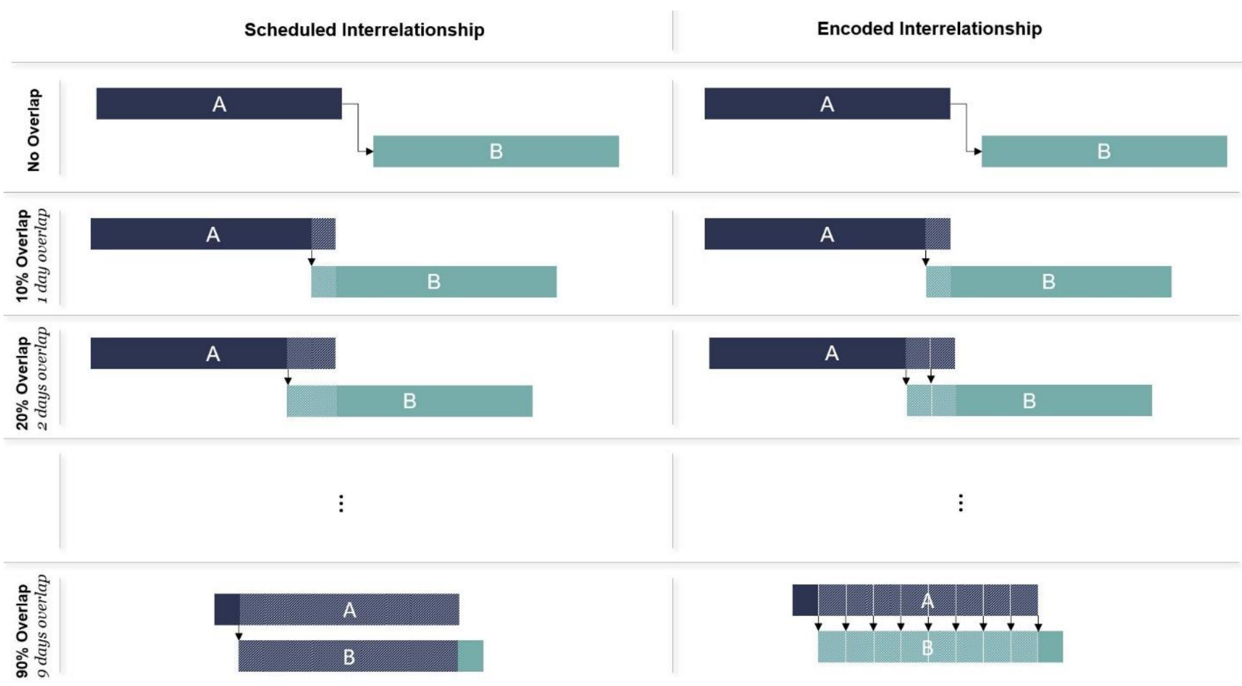


**Fig. 2.** Increasing overlap from 0% to 90% and dividing activities into sub-activities.

Based on the restrictions presented in Equations 1 to 6, the allowable regions for $v$ and $k$ are drawn. A point-grid with increments of 0.05 is created to identify the possible shapes of the beta-distribution in the $(v, k)$ plane. The point-grid, which is shown in Fig. 3, resulted in the identification of 233 different shapes of the beta-distribution.

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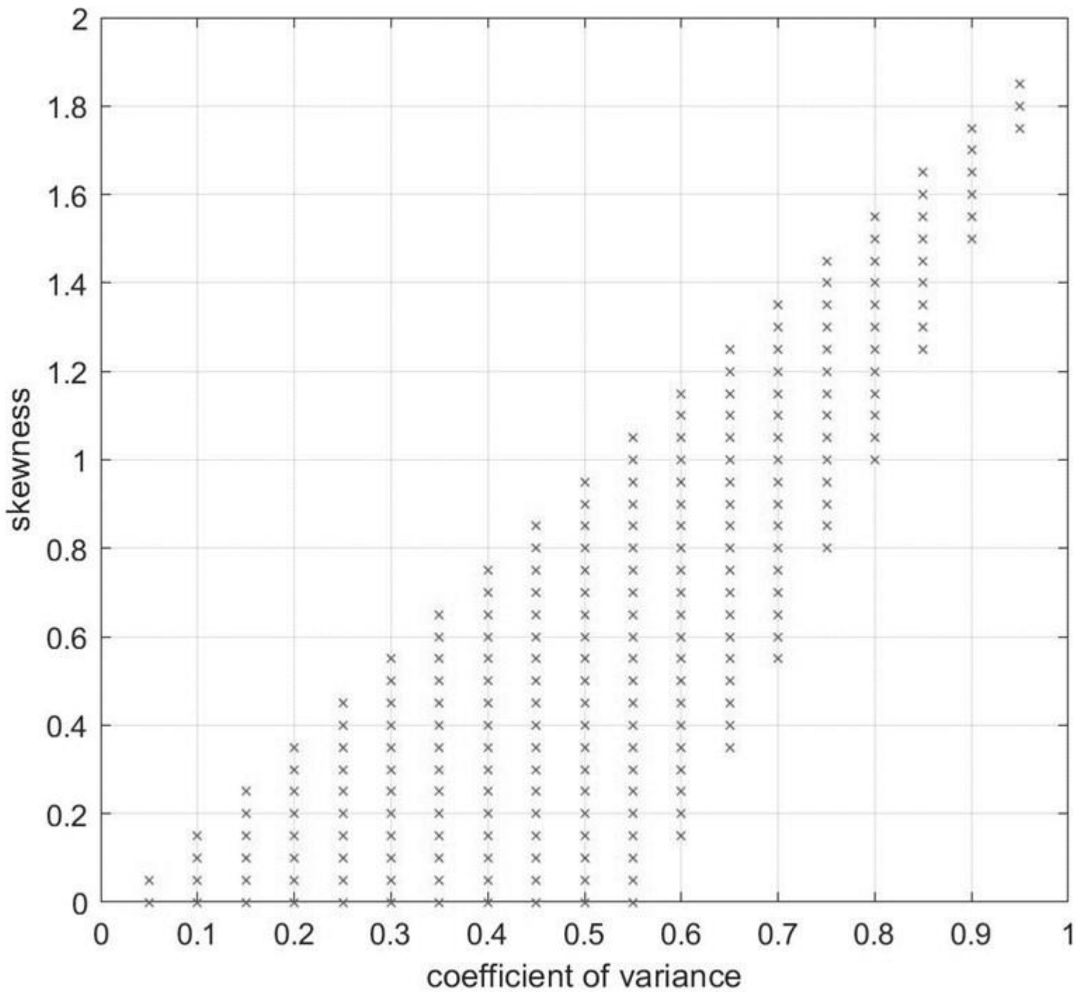


**Fig. 3.** The identified 233 beta-distributions placed in the allowable region of the (v, k) plane.

In order to investigate the impact of overlapping activities, the study carried out simulations that accounted for the various distinct shapes of the beta-distribution. To achieve this, every possible combination was considered, resulting in 54,056 unique combinations of activity A and activity B. The simulation of each degree of overlap (for 10 different degrees) was then conducted 10,000 times, resulting in a total of 5,405,600,000 calculations of the combined duration of activities A and B. The simulation was repeated while varying the duration ratio between activities A and B. A part of the study is to identify the best and worst combinations of distribution functions. Therefore, after identifying these combinations, additional simulation runs were conducted (1,000,000) to identify the mean in the BC and WC scenarios, to make sure that the findings converge.

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# 6 RESULTS & ANALYSIS

## 6.1 Impact on Duration

The effect of using overlapping activities is assessed in terms of effect on duration. Fig. 4 illustrates the changes in the PDFs as a function of Duration, representing the time between the initiation of activity A and the completion of activity B. This is demonstrated while progressively increasing the overlap from 0% to 90%. The longest recorded duration is 12 days, but it is not shown to allow for a more visually readable graph.

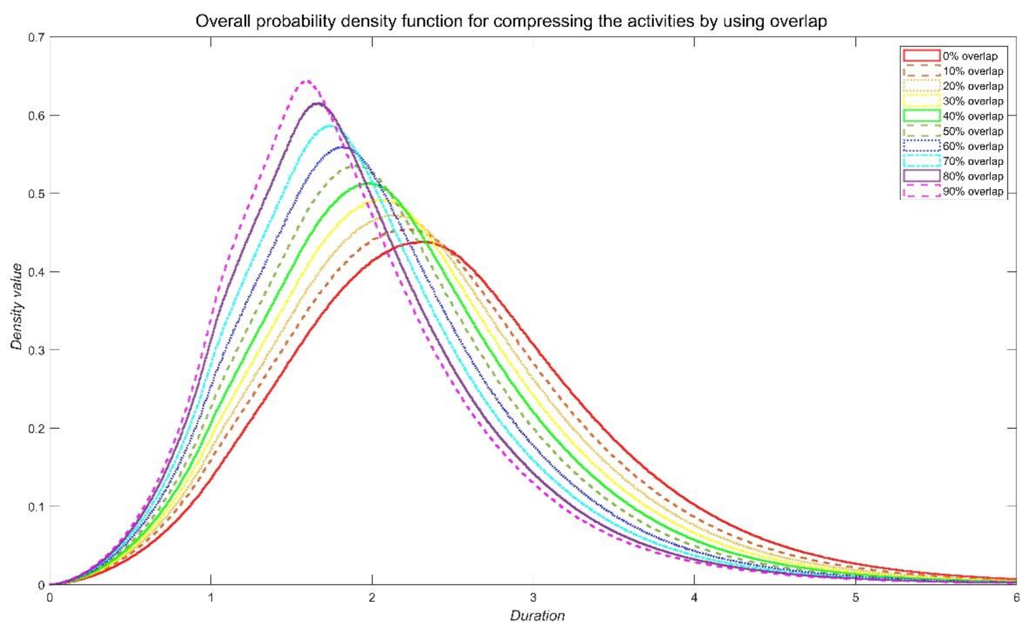


**Fig. 4.** The PDFs based on degree of overlap. Each function is based on a normalized histogram of the durations from all 54,056 combinations of PDFs.

Fig. 4 displays PDFs that have been generated from 10,000 simulations of all 54,056 distinct combinations of activities A and B's distribution functions. The PDFs exhibit a positive skew. By examining how the PDFs change with the degree of overlap between activities A and B, it becomes clear that an increase in overlap results in a decrease in the mean duration. This suggests that, across all possible combinations of activities A and B, an increase in overlap tends to have a positive effect on the duration of the activities.

In order to better understand the impact of overlapping on activity durations, additional analysis was conducted to examine the effects on WC, mean, and BC durations. The WC duration represents the mean of the worst possible duration combination of the activities' distributions, while the BC duration represents the mean of the best possible duration combination of distributions, and the mean duration represents the total average duration for all possible combinations. To evaluate the effect of overlap, changes in duration were compared to the expected mean duration, which was calculated using a classic deterministic approach. For example, since each activity was set to have a duration of one unit in this study, the expected mean duration was 2 units when conducting the activities in series. With a 10% overlap, activity B starts when 90% of activity A is completed, resulting in an expected duration of 0.9 + 1 = 1.9 units. Fig. 5 provides a

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closer examination of the effects of overlap on durations. It compares the mean values of each of the 54,056 combinations to the expected durations and plots them against the corresponding overlap percentage. This analysis provides further insight into how changes in overlap affect the duration of activities.

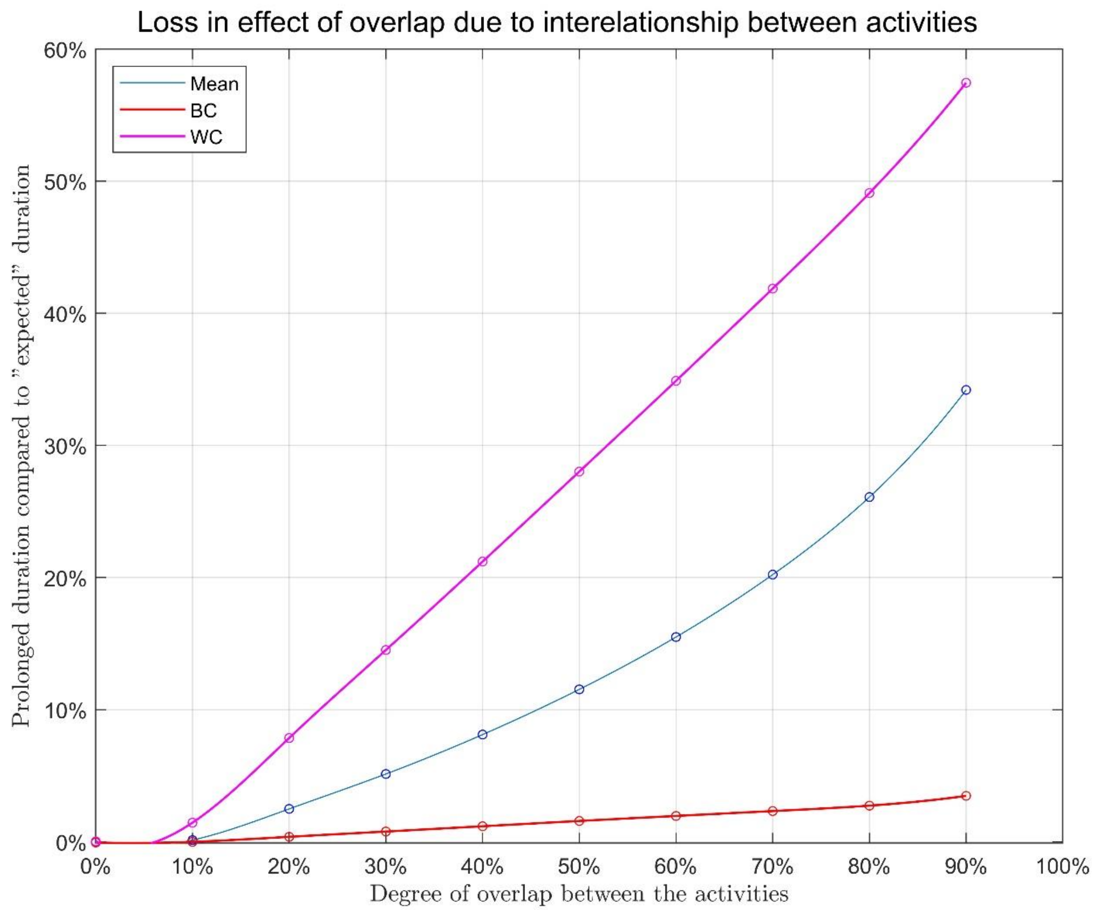


**Fig. 5.** Loss in effect of using overlapping activities due to the interrelationship between the activities.

Fig. 5 provides a clear illustration of the increasing loss in expected duration in response to overlap. The analysis reveals that, at a 90% schedule compression, the loss is 34.2% when examining the mean duration, 57.5% when examining the mean WC scenario, and 3.5% when examining the mean BC scenario. Even in the BC scenario, the mean duration is still 3.5% longer than expected. This is due to the impact of variability on the schedule, and other factors such as congestion may further exacerbate this effect. It is a common assumption that overlapping activities will result in a one-to-one reduction in duration. However, the results clearly show that one should expect a loss in effect to obtain a more realistic schedule. Therefore, as a practice, it is recommended to adjust the gains in accordance with the expected mean loss which depends on the degree of overlap as shown in Fig. 5. Moreover, the project manager should be aware of the diminishing returns associated with increased overlapping.

Salhab, D., Lindhard, S. M. and Hamzeh, F., 2024, "Simulation-Based Approximation of the Gain from Applying Overlapping Activities", Journal of Construction Engineering and Management, vol. 150, no. 4, pp. 04024019. https://doi.org/10.1061/JCEMD4.COENG-14166

To clearly illustrate the diminishing effect of increased overlapping, the gain percentage as a function of increasing the overlap by 10%, from 0% to 90%, is shown in Fig. 6.

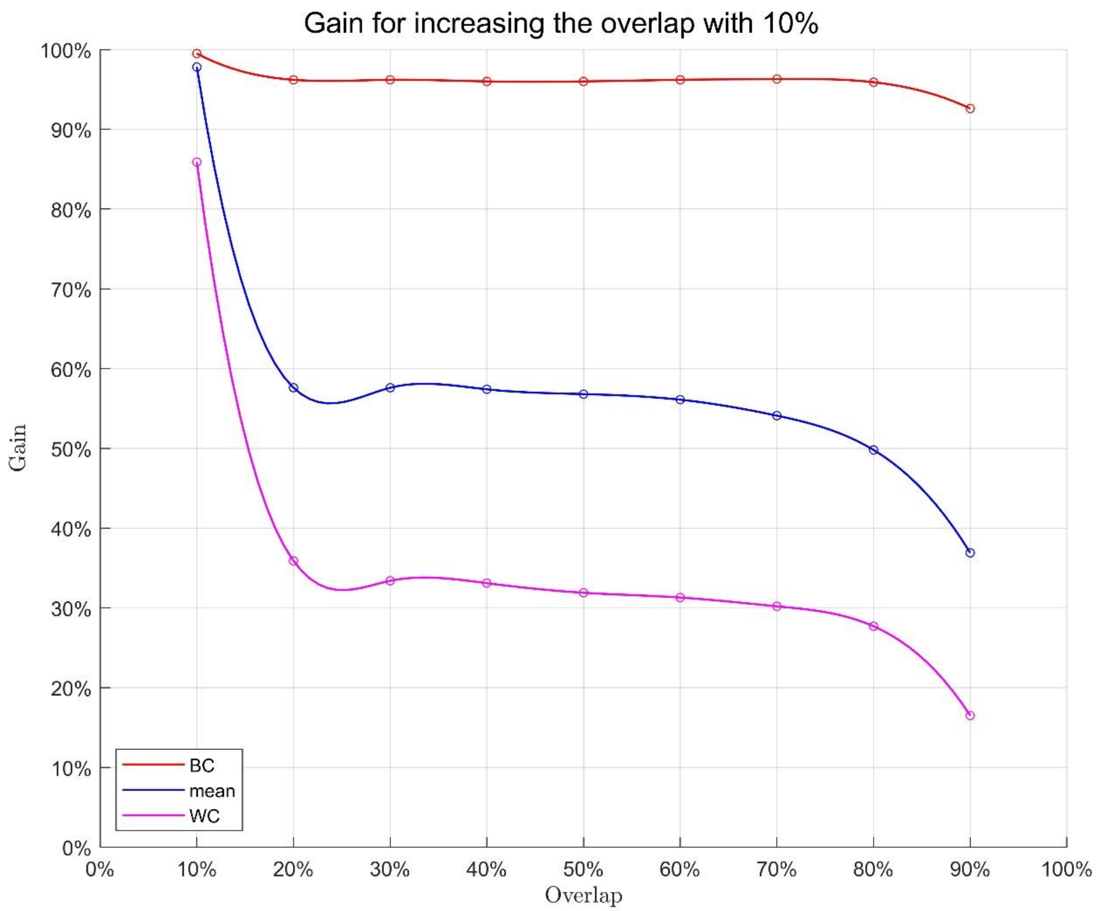


**Fig. 6.** The actual gain of increasing the overlap with an extra 10%.

The calculations reveal that the gain in the mean BC is close to one. That means even when increasing the overlap from 80% to 90%, the BC gain remains at 92.6%. There exists a large correlation between the overall loss in effect as depicted in Fig. 5 and the gain percentage as function of the degree of overlap. Thus, the high gain level confirms the low loss levels previously identified in the BC scenario. On the other hand, the gain in the mean WC duration is comparatively lower, and it decreases from an initial 85.93% when the overlap is increased from 0% to 10%, to a 16.5% when the overlap is increased from 80% to 90%. The results show that the overall loss in WC is more than that of mean which is in turn more than the loss in the BC scenario. However, since the actual distribution functions of activities A and B are often unknown, it is difficult to determine the actual schedule gain. Nevertheless, regardless of the distribution functions, the gain from increasing the overlap from 80% to 90% ranges from 16.5% to 92.6% depending on the combination of A and B's distributions. Given the substantial variation, the mean value can serve as an approximation of the effect. The mean represents the average effect across all 54,056 different combinations

Salhab, D., Lindhard, S. M. and Hamzeh, F., 2024, "Simulation-Based Approximation of the Gain from Applying Overlapping Activities", Journal of Construction Engineering and Management, vol. 150, no. 4, pp. 04024019. https://doi.org/10.1061/JCEMD4.COENG-14166

of activity A and B distributions. The mean gain of increasing the overlap from 80% to 90% is 36.9%. It is worthy to note that a small overlap of 10% is very efficient and has a high gain percentage even in the WC scenario, but when increasing the overlap to 20%, the effect drops immediately. The drop in gain percentage is probably due to the interrelationship between the overlapping activities where the succeeding activity often creates a delay while trying to catch up with the previous one. Further analysis would be needed to determine the root cause of this phenomenon.

Put simply, assuming that the schedule gain is directly proportional to overlapping is a misconception. There is an overlapping penalty that should be taken into consideration. Particularly, the effect from overlapping or the delay increases as the variation in the distribution functions increases.

### 6.2 The Variation Effect

This section examines variability, manifesting as schedule variation, across the different combinations. The analysis is conducted at 90% overlap because such overlap degree should reveal the biggest deviations in duration across the combinations of distributions. The effect of the overlap can be depicted in a series of scatter plots containing all possible distributions placed in the $(v, k)$ plane. Fig. 7 contains the mean of these scatter plots, and thus, represents the mean of all combinations of activity A's distributions compared to all combinations of activity B. The plot illustrates the effect on the duration with respect to variance and skewness in the form of deviation from expected mean. More specifically, when two activities have a 90% overlap, their expected mean duration is 1.1 units. The deviation from this expected mean is calculated by subtracting it from the actual duration. Therefore, a positive deviation indicates that the duration is longer than expected. The 'mean deviation from the expected mean' represents the average deviation over all 10,000 simulation runs.

Salhab, D., Lindhard, S. M. and Hamzeh, F., 2024, "Simulation-Based Approximation of the Gain from Applying Overlapping Activities", Journal of Construction Engineering and Management, vol. 150, no. 4, pp. 04024019. https://doi.org/10.1061/JCEMD4.COENG-14166

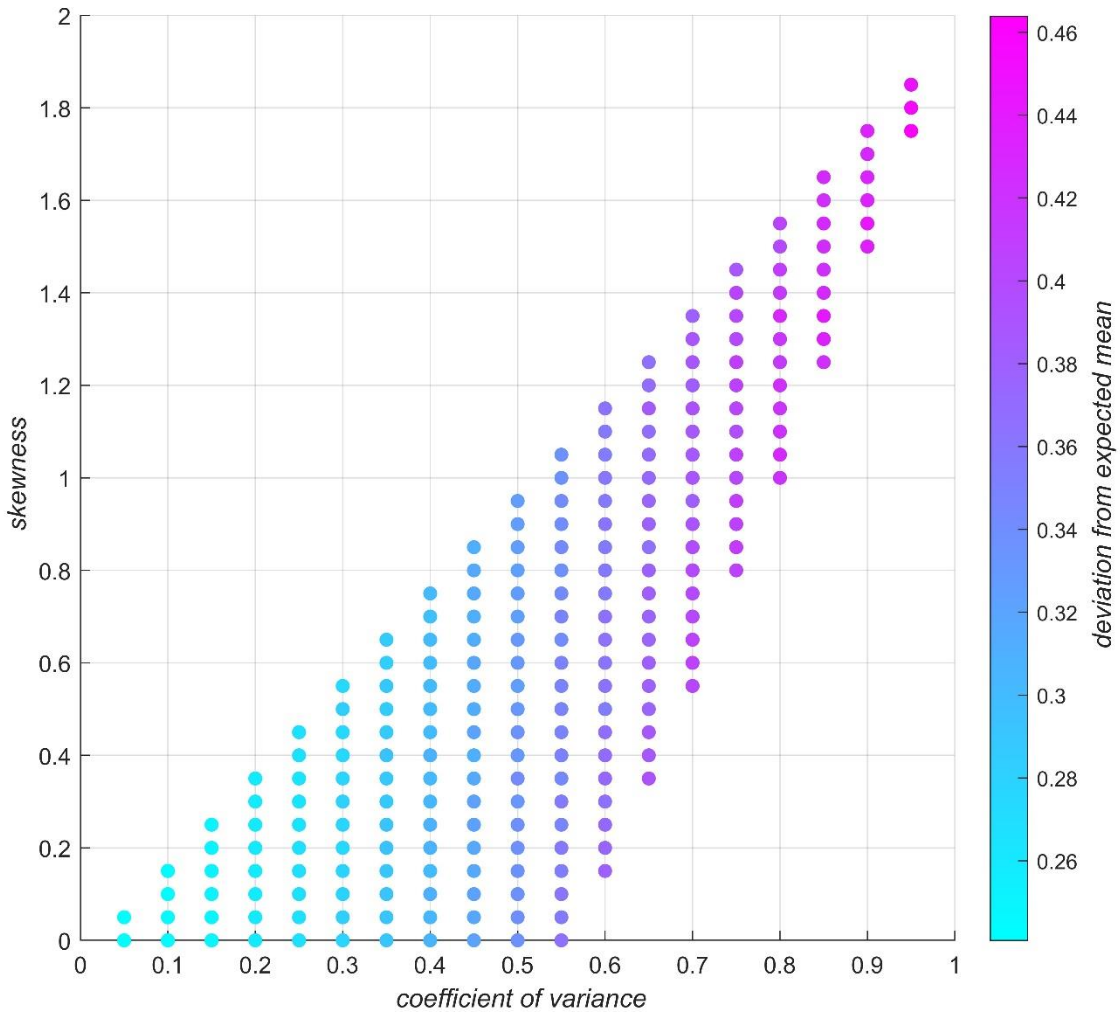


**Fig. 7.** The mean relative deviation from mean, depending on the skewness and coefficient of variance of activity B.

As the plot demonstrates, the previously identified loss in effect of the overlap is once again confirmed, where the relative deviation between simulated and expected mean values varies from 24.08% to 45.13%. Moreover, the plot clearly illustrates that it is the variance of the distribution function that is causing the loss in effect of the overlap.

Therefore, the lower the variability of the distributions of activities A and B, the closer the actual duration is to the expected duration. Thus, the mean BC scenario will be achieved when combining two distributions of low variability. Fig. 8a depicts this, where the variability of activity A is set to be as low as possible. In Figure 8b, the variability of activity A is set to be as high as possible, representing the mean WC scenario of A.

Salhab, D., Lindhard, S. M. and Hamzeh, F., 2024, "Simulation-Based Approximation of the Gain from Applying Overlapping Activities", Journal of Construction Engineering and Management, vol. 150, no. 4, pp. 04024019. https://doi.org/10.1061/JCEMD4.COENG-14166

**Placement of Fig. 8a and 8b.**

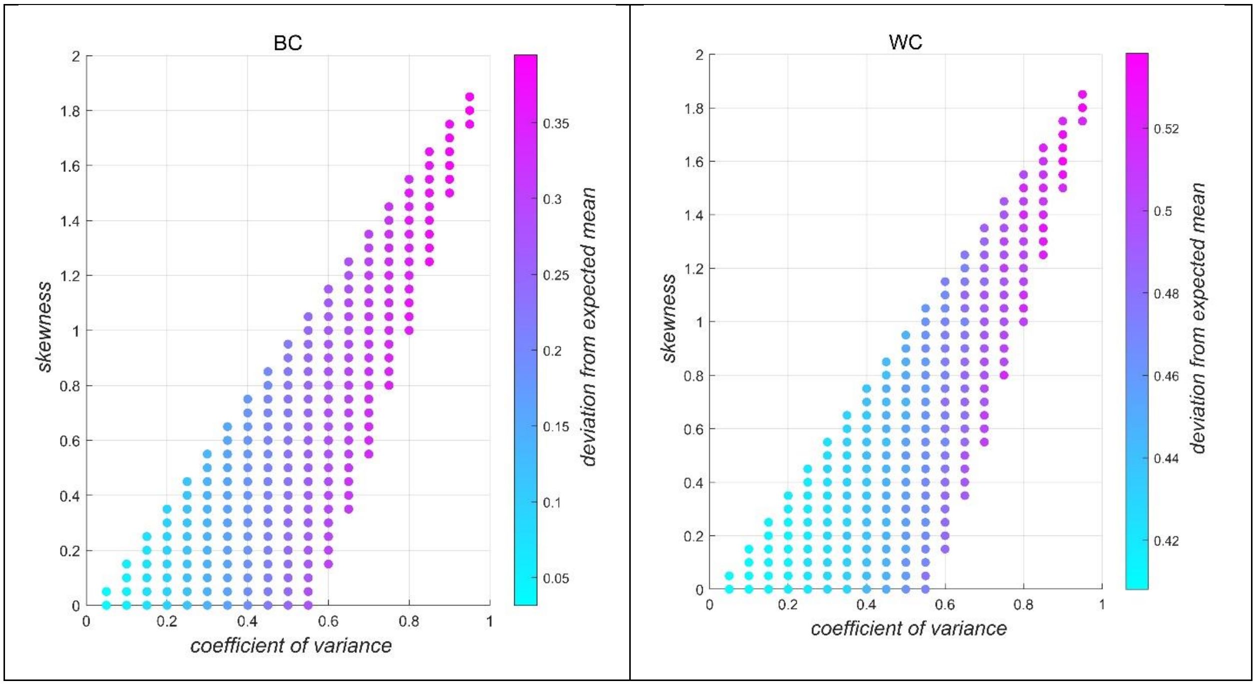


**Fig. 8.** The mean relative deviation from the expected mean duration of activity A's BC and WC beta-distributions.

Fig. 8a and Fig. 8b represent the BC and WC scenarios of activity A respectively. In the BC scenario, the relative deviation from expected mean duration ranges between 3.13% and 40.15%, while the deviation in the WC scenario of A ranges between 38.97% and 52.47%.

It follows that, even in the best possible scenario, the classic deterministic approach of just summing the expected durations, is underestimated by 3.13%. Moreover, the mean difference is 34.2% longer in duration than expected, which is quite significant.

This effect is significant to practitioners carrying out scheduling. If the effect is not considered, the overall project duration will be underestimated, and thus, the risk of delay will be increased. Consequently, if overlaps are used massively, it will be difficult to deliver the project on schedule.

In order to accommodate the effect of overlapping, a simulation of the mean loss in effect has been calculated while both the degree of overlap and the ratio between durations of the two activities have been varied. The result is shown in the diagram presented in Fig. 9 and depicts the mean expected loss across all possible combinations of distribution functions in the allowable region of the $(v, k)$ plane; it acts as an approximation to correcting the expected gain when applying overlapping and can be used even with unknown probability distribution functions.

Salhab, D., Lindhard, S. M. and Hamzeh, F., 2024, "Simulation-Based Approximation of the Gain from Applying Overlapping Activities", Journal of Construction Engineering and Management, vol. 150, no. 4, pp. 04024019. https://doi.org/10.1061/JCEMD4.COENG-14166

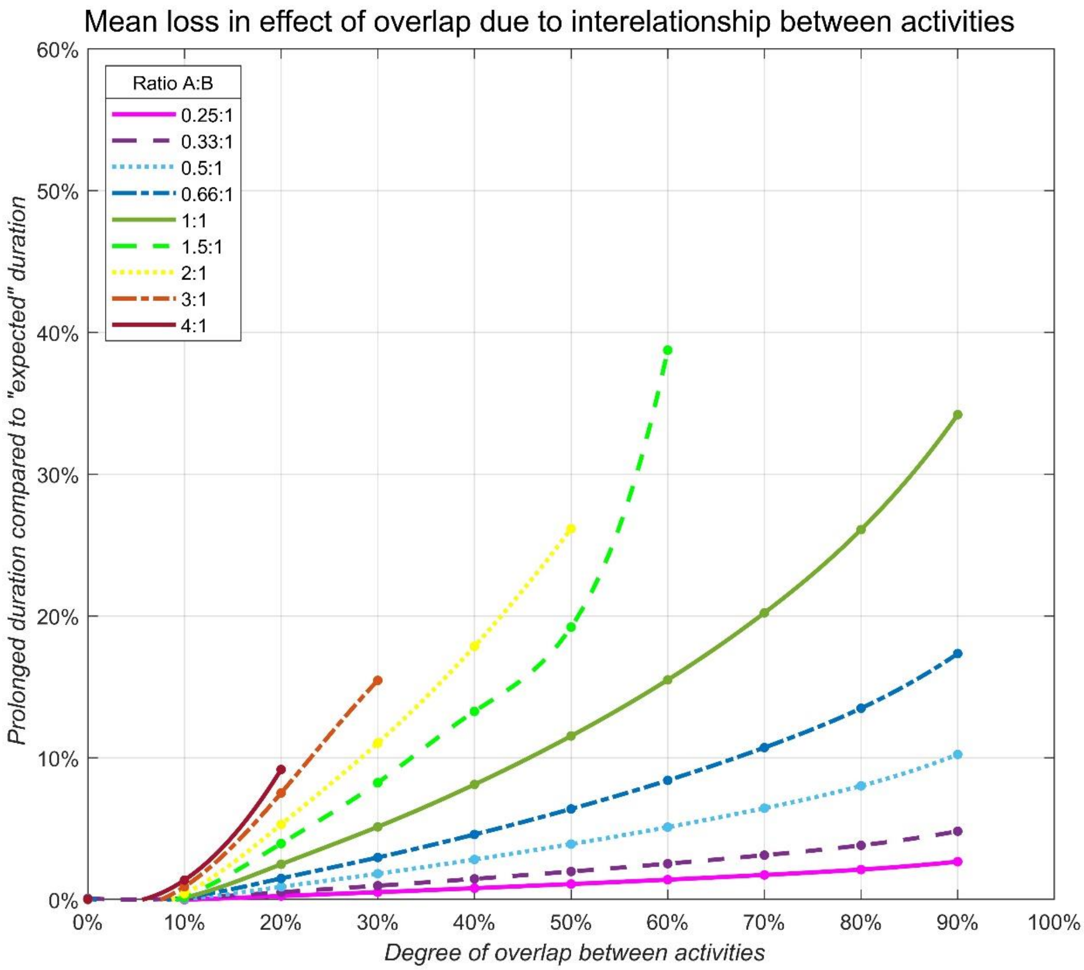


**Fig. 9.** The mean loss in effect of using overlapping due to variation and interrelationships between activities, depending on the ratio between the durations of the two activities (A and B).

The expected gain of applying overlapping can be calculated using the diagram presented in Fig. 9. First, the ratio between the durations of the overlapping activities needs to be calculated. Based on this ratio, the correct graph is identified. For instance, if activity A has a mean duration of 2.00 units while activity B has a mean duration of 1.00 unit, then the ratio is 2:1. Using the provided graph, the degree of overlap is selected and based on that the loss in effect is estimated. If a 50% overlap is applied, the mean loss in effect is approximately 26%. The effect of compressing the schedule is thus 26% lower than expected. A corrected mean duration can therefore be calculated by multiplying the expected duration achieved through deterministic scheduling with 126 %. In the given example, this means that the expected duration of B is 1.26 units instead of 1 unit.

In the presented example with a ratio of 2:1, it does not make sense to apply an overlap of over 50%. With a 50% overlap, activity B will start when activity A is half-completed. With durations based on the mean

Salhab, D., Lindhard, S. M. and Hamzeh, F., 2024, "Simulation-Based Approximation of the Gain from Applying Overlapping Activities", Journal of Construction Engineering and Management, vol. 150, no. 4, pp. 04024019. https://doi.org/10.1061/JCEMD4.COENG-14166

values of classical deterministic approach, the activities are expected to be completed simultaneously. Put simply, an increased overlap is no longer shortening the expected mean duration, this is also why in Fig. 9, the 2:1 ratio graph does not contain correction values for more than a 50% overlap.

The diagram presented in Fig. 9 can be used to calculate the actual effect on duration, every time overlapping is used to speed up production. Thus, by including the expected loss in every overlapping activity, a more realistic schedule can be achieved. This said, the estimated loss will be conservative because it only includes the effects of interrelationships and variation, thus disregarding the effects of congestion or managerial decisions.

# 7 DISCUSSION

The findings from this study provide valuable insights into the effect of overlapping activities on the duration of project activities. Reflecting on these findings, several key points emerge. Firstly, the results clearly demonstrate that increasing overlap tends to reduce the mean duration of activities. This suggests that overlapping activities can lead to a compression of the schedule and potentially expedite project completion. This finding is significant for project managers and practitioners who aim to optimize project schedules and improve efficiency. However, it is important to note that the study reveals diminishing returns associated with increased overlap. With only one overlap consisting of two isolated activities considered, the loss in expected duration indicates that even in the best-case scenario, the duration may be longer than initially anticipated, so how about with a more complicated schedule containing multiple activities? The loss will be much higher. This highlights the need for caution when relying solely on overlapping activities to achieve the shortest possible project duration. It is crucial to account for the potential loss and adjust expectations accordingly. It is recommended to estimate the actual gain by applying the established formulas whenever the schedule includes overlapping activities. While it may provide a conservative estimate, this approach ensures that the schedule is appropriately adjusted to account for any potential loss in effectiveness.

Moreover, the study addresses the schedule gain achieved by different overlap percentages. The results indicate that the gain in the mean BC scenario is relatively high, while the gain in the mean WC scenario is lower. This implies that overlapping activities may have a more positive impact on activities with lower variability and less uncertainty. The analysis consequently demonstrates that the impact of variability is a key factor influencing the effect of overlap. As the variability of the distribution functions of activities A and B increases, the loss in duration becomes more obvious. The notion that variability plays a significant role in the effect of overlap is also in line with prior studies. Variability in activity durations can lead to increased uncertainty and a higher likelihood of disruptions when activities are overlapped. Research by Arashpour and Arashpour (2015), Garcia-Lopez and Fischer (2016), and others examined the impact of variation in activity durations on construction project schedules and found that higher variability can amplify the negative effects on project performance, leading to schedule delays and cost overruns. This highlights the importance of considering the variability of activities when deciding to implement overlapping strategies.

This finding emphasizes the need to consider the specific characteristics and uncertainties associated with each activity when planning overlapping activities. Project managers should carefully analyze the variability and interrelationships of activities to better understand the potential risks and challenges that may arise. Therefore, understanding the specific characteristics of activities, and their distributions is crucial for accurately estimating the schedule gain achievable through overlapping. As the results suggest, there is a loss in the schedule due to overlapping. One possible explanation could be that performing multiple tasks on a unit at the same time with different crews can decrease daily work efficiency. Typically,

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the impact on the crew working first is less significant compared to the crew working afterwards. A good practice is to calculate the daily efficiency of crews when implementing activity overlapping to establish more accurate schedules as Biruk and Rzepecki (2021) did where they studied the influence of process simultaneity on project duration and working time of crews considering the variability of their daily efficiency.

Additionally, it is worth noting that in certain methodologies like takt planning, where construction activities and their durations are tightly linked, the understanding and management of overlap becomes especially vital. In takt scenarios, low variability is often assumed to maintain a predictable flow of work (Frandson et al., 2014). Hence, the findings of this study become particularly relevant. Misunderstanding or misapplying overlapping in takt planning contexts, where activities and durations are interdependent, can have amplified consequences. Thus, the role of overlapping in such planning methodologies should be treated with extra caution and foresight.

Put simply, if overlapping must be implemented, variability should be reduced to account for the penalty resulting from overlapping in the form of schedule loss. Resorting to certain practices such as adding more laborers without understanding reasons and impacts of variability might not be rewarding. Therefore, it is important to understand the lingering variability and take corresponding actions to remedy it. This could also be done through directly altering the distribution parameters by hiring more skilled workers, harnessing collaboration, increasing knowledge, providing a better working environment, etc. One suggested strategy to adopt is to use the Last Planner System when implementing activity overlaps. LPS is a production control mechanism used in Lean Construction to tackle variability through increasing planning reliability and improving project performance. Even with LPS, variability must be closely monitored as it was found in a study done by Alarcón and Zegarra (2012), that there exists a Bullwhip Effect between LPS variables, which refers to the amplification and distortion of variability in the upstream steps of a supply chain. Studying the Bullwhip Effect during the LPS process provides insights into the variability of managerial actions. This understanding can help quantify and proactively address variability generation during the LPS process. Also, the proper implementation of lookahead planning, which is a fundamental aspect of LPS, reduces variability and risks by proactively identifying potential issues, improving coordination and collaboration, optimizing resource allocation, removing constraints, enhancing risk management, and increasing predictability and control over the project. It enables project teams to address challenges early, minimize uncertainties, and achieve better outcomes (Hamzeh et al., 2012).

One notable aspect that resonates with prior research is the diminishing returns associated with increased overlap. This finding is consistent with studies that have highlighted the presence of a threshold beyond which the benefits of overlapping activities start to diminish or even become counterproductive. For example, a study by Ballesteros-Pérez (2017) on construction projects found that while some overlap can lead to schedule compression, excessive overlap can introduce risks and disruptions that offset the potential gains. These findings suggest the need for a careful balance when implementing overlapping activities.

After discussing the broader implications of overlapping activities, it is equally important to shed light on the more granular aspects of construction processes. An insightful tool in this domain is the crew-balance chart, borrowed from industrial engineering (Oglesby et al., 1989). This tool graphically represents the time allocation of each crew member and equipment, highlighting overlaps, idleness, and inefficiencies at a micro-level. Similar to the overarching principle of our study, these charts underscore that mere overlapping of tasks does not always equate to optimized productivity. Instead, it's the effective management of these overlaps, minimizing noneffective times, that can boost productivity. These micro-level observations further solidify this study’s macro findings, emphasizing that both at the task level and the broader project level, The precise planning of overlaps is paramount.

Salhab, D., Lindhard, S. M. and Hamzeh, F., 2024, "Simulation-Based Approximation of the Gain from Applying Overlapping Activities", Journal of Construction Engineering and Management, vol. 150, no. 4, pp. 04024019. https://doi.org/10.1061/JCEMD4.COENG-14166

In conclusion, these findings challenge the common assumption that overlapping activities always result in the most optimistic duration. They highlight the need for a more comprehensive approach to project scheduling, considering the trade-offs, risks, and uncertainties associated with overlapping activities. Project managers should carefully balance the benefits and potential drawbacks of overlap, considering factors such as variation, complexity, and coordination. The analysis conducted so far has its limitations and can be viewed as a conservative estimate as it only considers the expected loss resulting from interrelationships and variability. However, the actual benefits of using overlap are likely to be even lower if additional factors such as increased complexity and overmanning are considered. Therefore, further research is necessary to estimate the effects of these factors. If underestimated, the consequences from overlapping could be more negative than initially anticipated, even without considering congestion and other related factors.

# 8 CONCLUSION

Overlapping activities is one approach used by practitioners to accelerate projects. The common understanding is that one unit of overlapping leads to a one-unit shorter duration. However, this is rarely the case. This paper aims to explore the schedule gains achieved from implementing activity overlaps. A simulation model that takes different degrees of overlaps and evaluates corresponding gains is developed and the effects of overlapping are demonstrated based on an isolated overlap consisting of two activities, A and B. The worst-case (WC), mean, and best-case (BC) durations were evaluated, and changes in duration were compared to the expected mean duration calculated using a classic deterministic approach. To reach a general conclusion, the model combines 233 different probability density functions that cover the entire allowable region of the (v, k) plane.

The results demonstrated a clear illustration of the increasing loss in expected duration in response to overlap. With a 1:1 ratio between activity durations at a 90% schedule compression, the loss ranged from 3.5% in the mean best-case scenario to 57.5% in the mean worst-case scenario with an overall mean loss of 34.2%. These findings highlight that even in the best-case scenario, the duration often is still longer than expected, indicating the impact of variation on the schedule. Also, the results showed that even the best scenario falls short of expectations, suggesting the need to add approximately 35% to the mean duration to obtain a more realistic outcome when applying overlapping of two activities. The recommendation is to add the loss associated with overlapping, every time overlapping is applied, by using the corrections from the diagram shown in Fig. 9.

The analysis also focused on the variation effect, examining the deviation in duration across different combinations of distributions. The results showed that the variance of the distribution was a significant factor causing the loss in the effect of overlap. Lower variability in the distributions of activities A and B resulted in durations closer to the expected values. The mean BC scenario was achieved when combining distributions with low variability, while the mean WC scenario occurred when combining distributions with high variability.

In summary, the findings of this study emphasize the importance of considering the loss in expected duration and the variation effect when using overlapping activities in scheduling. Ignoring these factors can lead to underestimating the overall project duration and increasing the risk of delays. The study highlights the need for practitioners to carefully manage overlapping activities to deliver projects on schedule. It is worth noting that the findings of this study provide valuable insights, but they are based on specific assumptions and analysis methods. Further research and real-world validation are necessary to corroborate and refine these findings. Also, the choice to exclude congestion and focus on schedule variation was made to isolate the impact of schedule variations without the confounding effects of congestion. While this

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approach simplifies the problem and allows for a focused analysis, it does introduce limitations such as in real-world scenarios, schedule variations and congestion often coexist, potentially compounding delays or inefficiencies. Thus, the results of this study might not capture the full complexity of situations where both factors are at play. Future research could consider developing a model that incorporates both schedule variation and congestion to provide a more holistic understanding. Nonetheless, the study highlights the importance of considering the effects of overlap and variability when planning and managing project schedules, ultimately contributing to more reliable project planning and execution. These insights are valuable for project managers and practitioners in various industries, providing guidance for more effective project scheduling and risk management.

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**Data availability statement**
Some or all data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request.

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