

Proyek konstruksi jalan tol merupakan salah satu jenis proyek dengan kompleksitas tinggi dan potensi ketidakpastian durasi yang signifikan pada setiap tahapan pekerjaan. Salah satu permasalahan yang terjadi adalah keterlambatan penyelesaian proyek, yang berdampak pada proyek secara keseluruhan. Penelitian ini bertujuan untuk menganalisis risiko keterlambatan pada pekerjaan struktur Zona 3 Proyek Jalan Tol Solo-Yogyakarta-NYIA Kulon Progo Paket 2.1 menggunakan penjadwalan probabilistik serta mengidentifikasi kontribusi ketidakpastian dari masing-masing sumber estimasi terhadap risiko keterlambatan proyek.

Data primer diperoleh melalui kuisisioner dan wawancara terhadap 15 responden ahli untuk mendapatkan estimasi durasi optimis, *most likely*, dan pesimis, sedangkan data sekunder diperoleh dari dokumen *time schedule* kontraktor dan studi literatur. *Baseline* jadwal proyek disusun menggunakan Microsoft Project berdasarkan durasi dan penjadwalan pihak kontraktor. Estimasi durasi tiap aktivitas hasil wawancara diinput ke Microsoft Project untuk memperoleh total durasi optimis, *most likely*, dan pesimis per responden yang selanjutnya digunakan sebagai input Simulasi Monte Carlo berbasis Python dengan pendekatan *random expert selection* dan distribusi Beta-PERT sebanyak 10.000 iterasi. Analisis reliabilitas responden dilakukan dengan mengelompokkan responden ke dalam tiga kategori, yaitu Akurat, Optimis, dan Pesimis, berdasarkan selisih nilai PERT terhadap jadwal *baseline* kontraktor, yang dikaitkan dengan karakteristik responden.

Hasil penelitian menunjukkan rata-rata durasi proyek 174,87 hari dengan standar deviasi 21,10 hari, serta persentil  $P50 = 174,06$  hari,  $P90 = 201,72$  hari, dan  $P95 = 210,43$  hari. Probabilitas jadwal kontraktor selesai tepat waktu hanya sebesar 33,8%, sehingga risiko keterlambatan proyek mencapai 66,2% dan tergolong kategori tinggi. Analisis reliabilitas responden mengidentifikasi 4 responden pada kategori Akurat, 2 responden pada kategori Optimis, dan 9 responden pada kategori Pesimis, dengan temuan bahwa ketiadaan Sertifikasi Kompetensi Kerja (SKK) cenderung berestimasi optimis, sedangkan jabatan yang berorientasi pada pengawasan mutu dan pengendalian teknis cenderung berestimasi yang lebih konservatif/pesimis. Penelitian ini mengintegrasikan Microsoft Project, Microsoft Excel, dan Python dalam satu alur analisis penjadwalan probabilistik, pendekatan *random expert selection* yang mempertahankan heterogenitas persepsi antarpakar, serta analisis reliabilitas responden sebagai pelengkap evaluasi ketidakpastian jadwal.

**Kata Kunci:** risiko keterlambatan, penjadwalan probabilistik, Simulasi Monte Carlo, distribusi PERT, reliabilitas responden, jalan tol.

*The toll road construction project is one type of project characterized by high complexity and a significant degree of duration uncertainty at each stage of work. One of the main problems that occurs is project delay, which affects the project as a whole. This study aims to analyze the risk of delay in the structural work of Zone 3 of the Solo-Yogyakarta-NYIA Kulon Progo Toll Road Project Package 2.1 using probabilistic scheduling and to identify the contribution of uncertainty from each estimation source to the risk of project delay.*

*Primary data were obtained through questionnaires and interviews with 15 expert respondents to determine optimistic, most likely, and pessimistic duration estimates, while secondary data were obtained from the contractor's time schedule documents and literature review. The project baseline schedule was developed using Microsoft Project based on the contractor's duration and scheduling plan. The duration estimates for each activity from the interviews were then input into Microsoft Project to obtain the total optimistic, most likely, and pessimistic durations per respondent, which were subsequently used as input for a Monte Carlo Simulation based on Python with a random expert selection approach and a Beta-PERT distribution for 10,000 iterations. Reliability analysis of the respondents was conducted by grouping them into three categories, namely Accurate, Optimistic, and Pessimistic, based on the difference between the results to respondent characteristics.*

*The results show an average project duration of 174.87 days with a standard deviation of 21.10 days, as well as  $P50 = 174.06$  days,  $P90 = 201.72$  days, and  $P95 = 210.43$  days. The probability of the contractor's schedule being completed on time is only 33.8%, so the project delay risk reaches 66.2% and is classified as high. The respondent reliability analysis identified 4 respondents in the Accurate category, 2 respondents in the Optimistic category, and 9 respondents in the Pessimistic category. The findings indicate that the absence of a Construction Skills Certification tends to be associated with optimistic estimates, while positions related to quality supervision and technical control tend to produce more conservative or pessimistic estimates. This study integrates Microsoft Project, Microsoft Excel, and Python into one analysis workflow, applies a random expert selection approach to preserve the heterogeneity of expert perceptions, and includes respondent reliability analysis as a complement to schedule uncertainty evaluation.*

**Keywords:** delay risk, probabilistic scheduling, Monte Carlo Simulation, PERT distribution, respondent reliability, toll road.