CONSTRUCTION ENGINEERING AND MANAGEMENT

Critical Path Method Adoption, Delay Factors and Schedule Crashing in Lagos Construction Projects: A Survey and a Proposed Six-Stage Framework

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Abstract

Background: Construction projects in Lagos State often finish late, although the Critical Path Method (CPM) is well established. Earlier Lagos studies ranked causes of delay but did not measure CPM adoption, delay on critical activities and the judged effectiveness of crashing in one sample. **Methods:** A cross-sectional questionnaire survey was carried out among engineers, builders, project managers and architects working in four Lagos local government areas. Of 250 questionnaires distributed, 99 were returned (39.6%), and 83 to 96 responses were valid for each analysis. Data were analysed with descriptive statistics, the Relative Importance Index, one-sample t-tests, Pearson correlation and one-way ANOVA. **Results:** CPM adoption (M = 3.72, SD = 0.90) and perceived crashing effectiveness (M = 3.61, SD = 0.77) were above the scale midpoint, with large effects (d ≈ 0.80). Among 16 delay factors, labour shortages and low productivity (M = 3.64), bad weather, design changes, equipment constraints and governance issues ranked highest. Agreement that compression follows cost-benefit analysis was only moderate (M = 3.41), and perceived crashing effectiveness was unrelated to adoption (r = .15, p = .156). Early contractor involvement (M = 4.09) was the most supported strategy. **Conclusion:** Lagos professionals report wide use of CPM, but training and cost-based recovery decisions are weak points. A six-stage framework is proposed for validation. The findings rest on perceptions from a non-probability sample and do not show that CPM reduces delay.

Keywords: construction delay; critical path method; Lagos State; project scheduling; schedule crashing

1 Introduction

Late completion is one of the most persistent problems in construction. Meta-analyses and reviews have catalogued hundreds of causes, and a small group of factors recurs across countries [1]–[3]. Studies of Lagos State, Nigeria's largest construction market, point to contractor finance, errors in scheduling decisions, corruption and bureaucratic delay [4]–[7]. Most of this work ranks causes. It says little about the planning method that is meant to control them.

The Critical Path Method (CPM) represents a project as a network of activities, calculates earliest and latest times, and identifies the activities with zero total float. A delay to any of these critical activities delays completion unless the plan is changed [8, 9]. The value of CPM therefore depends on the quality and currency of the schedule it contains. An audit of baseline schedules found that many fell short of recognized practice on float management and activity relationships [10], and classical network calculations give optimistic completion dates when durations vary [11]. When a critical activity slips, managers can shorten it by adding resources at extra cost, a measure known as crashing, and the choice among activities is a time–cost trade-off problem [12, 13].

Within the studies reviewed for this paper, none measured CPM adoption, the factors acting on critical-path activities, the judged effectiveness of crashing and the strategies practitioners support in a single sample of Lagos professionals. The closest study surveyed experts on delay from ineffective scheduling [5]. The present study addresses this gap. Its objectives were to (i) assess the extent of CPM adoption; (ii) rank the factors affecting critical-path activities; (iii) assess the perceived effectiveness of crashing; and (iv) identify the strategies respondents support for improving schedule performance. Five null hypotheses were tested: adoption and crashing effectiveness do not exceed the scale midpoint (H_{01}, H_{02}); the main indices are unrelated (H_{03}); and adoption and crashing do not differ by professional group (H_{04}) or by local government area (H_{05}). The paper reports perceptions of practice. It does not analyse project schedules, so it cannot show that CPM use shortens projects.

2 Methods

2.1 Design and study area

A cross-sectional descriptive survey with a quantitative approach was used. A survey suits the objectives because each asks about the extent of a practice or the strength of opinion, both measurable on rating scales [14]. A case study of planned and actual schedules was considered, but access to contract programmes across many firms was unlikely, and interviews would have reduced the number of cases. The survey therefore trades objective measurement for breadth. The sampling plan covered five local government areas (LGAs) with high construction activity: Eti-Osa, Ibeju-Lekki, Ikeja, Lagos Island and Alimosho.

2.2 Sampling and respondents

Purposive and snowball sampling were combined. Purposive sampling selected practitioners with relevant experience, and its credibility depends on stating how participants were chosen [15]. Snowball sampling then used referrals within professional networks. It reaches dispersed populations but gives members no known chance of selection [16], and it was chosen because no complete list of practising professionals existed. The results therefore describe the respondents and cannot be generalized statistically. The target group was civil and structural engineers, builders, quantity surveyors, and project or construction managers with at least five years of experience. Seven respondents reported less than five years. Their records were retained so that sample sizes match the analysed data.

A total of 250 questionnaires was distributed and 99 were returned (39.6%). Valid responses ranged from 83 to 96 per item because some respondents skipped questions, and each analysis reports its own sample size. Power analysis is the usual way to judge whether a sample can detect an effect of interest [17]. Thirty-four respondents give 80% power for a one-sample t-test at d = 0.50, and about 85 give 80% power for r = .30. A four-group ANOVA with a medium effect (f = 0.25) needs about 180 respondents, so the group comparisons here have power near 47% and are exploratory.

2.3 Instrument and reliability

A structured, self-administered questionnaire had five sections: respondent and organization characteristics; CPM adoption (seven statements and one frequency item); the influence of 16 factors on delay in critical-path activities; crashing (five statements); and eight improvement strategies. All rating items used a five-point scale (1 = lowest, 5 = highest). Items were adapted from the delay and scheduling studies cited above and from standard CPM texts [8]. Averaged Likert ratings were treated

as interval data, a practice supported for summed and averaged scales [18]. Two academics and two practitioners reviewed the draft for content validity. A pilot with 30 professionals gave an overall Cronbach's alpha of .87 with every section above .70. Alpha shows internal consistency and does not prove that a scale measures a single construct [19], so it is used here in the first sense only.

Two items are worded negatively (preference for traditional methods over CPM, and cost and resource limits restricting crashing). The indices reported here are those produced from the items as coded. The mean of the seven adoption item means is 3.72 as scored and 3.65 if the negative item is reversed. For the five crashing items the values are 3.69 and 3.54. Both indices stay above the midpoint under either coding, so the conclusions do not depend on this choice, although the exact values do. Self-reported practice is also open to social desirability bias [20]. This applies directly to the adoption items, because using CPM is the professionally expected answer. The questionnaire asked for no names or contact details to reduce the incentive to overstate.

2.4 Data analysis

Data were analysed in IBM SPSS Statistics version 26 with pairwise deletion of missing values. Descriptive statistics summarized each item. The adoption index is the mean of seven statements, the crashing index the mean of five, delay severity the mean of the 16 delay items, and strategy support the mean of eight items. Delay factors were ranked by the Relative Importance Index (RII), the sum of ratings divided by the highest rating (5) times the number of respondents [21]. On a five-point scale RII equals the mean divided by 5, so ranking by either gives the same order. One-sample t-tests compared the adoption and crashing indices with the midpoint of 3.00. Pearson correlation examined the relationships among adoption, delay severity and crashing effectiveness, and one-way ANOVA with Levene's test compared indices across professional groups and LGAs. All tests were two-tailed at $\alpha = .05$. Cohen's d was calculated as $(M - 3.00)/SD$, η^2 as $(F \times df_1)/(F \times df_1 + df_2)$, and correlation confidence intervals by Fisher's z transformation, all from the reported statistics. Conventional benchmarks guide interpretation, with the caution that effects should be read against the field [22]. Where Levene's test was significant, Welch's F with Games-Howell comparisons is preferred [23], [24]. Only the standard ANOVA output was available, so those results are reported as provisional.

2.5 Research ethics

The study followed the principles of informed consent, confidentiality, minimal risk and honest reporting. Ethical clearance was obtained from the School of Postgraduate Studies, University of Ibadan, reference REC/2025/04/CPM-01, dated March 10, 2025. Each respondent received an information sheet stating the purpose, that participation was voluntary and that they could skip questions or withdraw before submitting. Completing the questionnaire was taken as consent. No names, company names or contact details were collected, responses were coded, and data are reported only in aggregate, in line with the Nigeria Data Protection Act [25]. Data were collected between March and May 2025.

3 Results

3.1 Respondents

Table 1 summarizes the respondents. Civil and structural engineers were the largest group (53.8%), and 92.7% of respondents had at least five years of experience. Contractors made up 55.2% of the sample and 52.1% handled projects above ₦2 billion. The sample is uneven in location: Eti-Osa

supplied 71.1% of valid responses and Alimosho supplied none. No quantity surveyor appears in the data.

Table 1. Respondent characteristics.

Variable (valid N)	Category	f	%
Profession (93)	Civil/structural eng.	50	53.8
	Project/constr. manager	22	23.7
	Builder	18	19.4
	Architect	3	3.2
Experience (96)	< 5 years	7	7.3
	5–10 years	29	30.2
	11–15 years	32	33.3
	16–20 years	10	10.4
	> 20 years	18	18.8
Organization (96)	Contractor	53	55.2
	Client/developer	19	19.8
	Consultant	12	12.5
	Government agency	12	12.5
LGA (90)	Eti-Osa	64	71.1
	Lagos Island	12	13.3
	Ikeja	8	8.9
	Ibeju-Lekki	6	6.7
Project value (96)	> ₦2 billion	50	52.1

Note. Valid percentages. LGA = local government area.

3.2 Extent of CPM adoption

The adoption index had a mean of 3.72 (SD = 0.90, N = 96). A one-sample t-test showed it was significantly above the midpoint, $t(95) = 7.86$, $p < .001$, with a mean difference of 0.72, 95% CI [0.54, 0.90], and a large effect ($d = 0.80$). H_{01} is rejected. Table 2 lists the items. Respondents agreed most that CPM identifies critical activities, dependencies and float (M = 4.20) and least that project teams receive CPM training (M = 3.59 among the positively worded items). The negatively worded statement that traditional methods are preferred over CPM scored 3.27, above neutral. The frequency-of-use item had a mean of 3.93 (SD = 1.02).

Table 2. Adoption and crashing: item and index statistics.

Statement	N	M	SD
CPM adoption index	96	3.72	0.90
CPM identifies critical activities and float	96	4.20	1.05
CPM used in all project phases	96	3.82	1.33

Statement	N	M	SD
CPM optimization used with software	96	3.75	1.28
CPM is main scheduling method	93	3.72	1.29
CPM regularly updated	93	3.72	1.22
Staff receive CPM training	96	3.59	1.18
Traditional methods preferred[a]	96	3.27	1.18
Crashing effectiveness index	93	3.61	0.77
Overtime, manpower or other techniques used	90	3.93	1.19
CPM supports time–cost trade-off	87	3.90	0.97
Crashing can rescue project time	90	3.83	1.33
Compression follows cost-benefit analysis	83	3.41	0.99
Cost and resource limits restrict crashing[a]	87	3.38	1.08

Note. Scale 1–5. [a]Negatively worded item. Index tests against 3.00: adoption $t(95) = 7.86$, $d = 0.80$; crashing $t(92) = 7.64$, $d = 0.79$ (both $p < .001$).

3.3 Factors affecting critical-path activities

Figure 1 ranks the 16 delay factors by mean score. Labour shortages or low productivity ranked first (M = 3.64, RII = 0.728), followed by bad weather (3.42), design changes or scope variations (3.41), unavailable or expensive equipment (3.36) and corruption or governance issues (3.29). Poor planning or scheduling (2.96) and inaccurate activity-duration estimates (2.80) ranked 11th and 15th, and client dissatisfaction ranked last (2.74). Only the first ten factors had means above 3.00, and the tenth was 3.01. Standard deviations were not available for these items, and neighbouring ranks differ by as little as 0.01, so the ranking is better read as higher and lower groups than as a strict order. The list did not include late payment or contractor cash flow, so the ranking covers the 16 listed factors only.

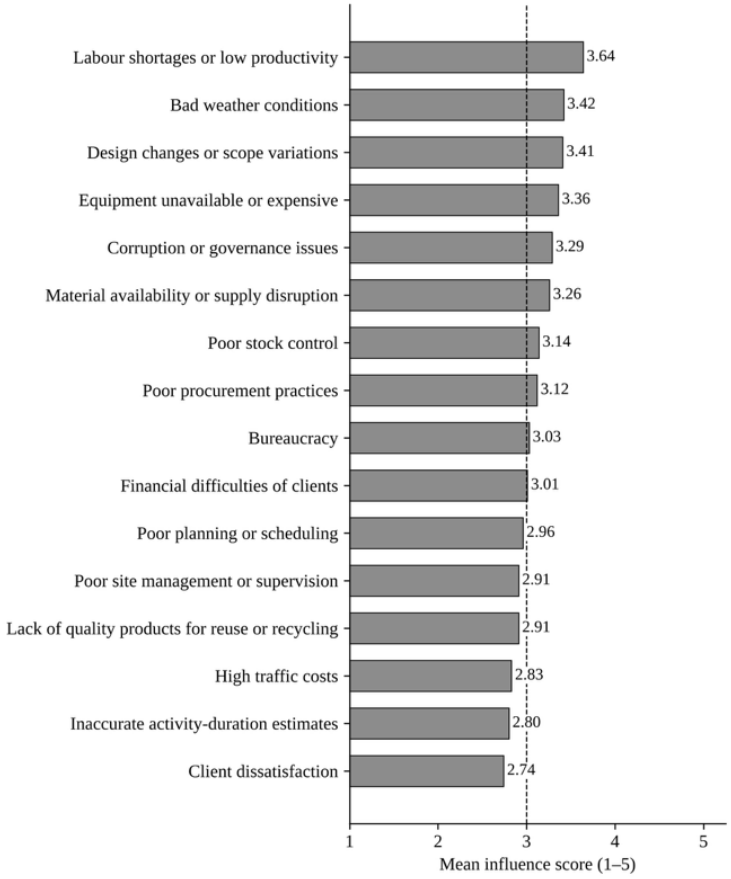


Figure 1. Mean influence scores for the 16 delay factors on critical-path activities (scale 1–5; RII = mean/5).

3.4 Perceived effectiveness of crashing

The crashing index had a mean of 3.61 (SD = 0.77, N = 93), significantly above the midpoint, $t(92) = 7.64$, $p < .001$, mean difference 0.61, 95% CI [0.45, 0.77], $d = 0.79$. H_{02} is rejected. Respondents agreed most that overtime, extra manpower or alternative techniques are used with CPM to reduce delay (M = 3.93) and that CPM supports time–cost trade-off decisions (M = 3.90). Agreement was lower that schedule compression follows cost-benefit analysis (M = 3.41) and that cost and resource limits restrict crashing (M = 3.38) (Table 2).

3.5 Relationships among the main indices

Table 3 gives the correlations. Adoption correlated weakly with delay severity ($r = .25$, $p = .014$) and delay severity correlated moderately with crashing effectiveness ($r = .50$, $p < .001$). Adoption and crashing effectiveness were not significantly correlated ($r = .15$, $p = .156$), and the interval includes zero. H_{03} is rejected for two of the three pairs. These are associations and do not show direction or cause.

Table 3. Pearson correlations among the main indices.

Pair	r	95% CI	p	N
Adoption × delay severity	.25	[.05, .43]	.014	96
Adoption × crashing effectiveness	.15	[−.06, .34]	.156	93
Delay severity × crashing effectiveness	.50	[.33, .64]	< .001	93

Note. CI by Fisher's z transformation.

3.6 Supported strategies

The strategy index had a mean of 3.85 (SD = 0.97, N = 96). Early contractor involvement in planning ranked highest (M = 4.09), followed by daily delay analysis (3.90), better government policies for approvals and financing (3.86), software support with mandatory CPM training for small and medium enterprises (3.82), and hybrid CPM with BIM or AI-based scheduling (3.75). Integrated CPM with PERT or Monte Carlo simulation (3.69) and CPM with as-built and time impact analysis (3.67) ranked lowest. All eight means lie within 0.42 of each other, so respondents supported every strategy and the ranking is informative mainly at the top.

3.7 Differences by professional group and LGA

Adoption differed by professional group, $F(3, 89) = 4.49$, $p = .006$, $\eta^2 = .13$, and by LGA, $F(3, 86) = 8.02$, $p < .001$, $\eta^2 = .22$ (Table 4). Architects had the highest adoption (M = 4.71, n = 3) and builders the lowest (3.17, n = 18). Eti-Osa was highest among LGAs (4.00, n = 64) and Ikeja lowest (2.64, n = 8). Perceived crashing effectiveness also differed by group, $F(3, 86) = 3.10$, $p = .031$, and by LGA, $F(3, 83) = 5.14$, $p = .003$. Builders gave the highest crashing rating (4.04) and Ikeja the highest among LGAs (4.53). H_{04} and H_{05} are rejected. Levene's test was significant for three of the four comparisons, so these results are provisional, and the groups of 3, 6 and 8 respondents rest on very few people.

Table 4. One-way ANOVA by professional group and LGA.

Outcome	Grouping	F (df)	p	η^2	Levene p
Adoption	Profession	4.49 (3, 89)	.006	.13	< .001
Adoption	LGA	8.02 (3, 86)	< .001	.22	< .001
Crashing	Profession	3.10 (3, 86)	.031	.10	< .001
Crashing	LGA	5.14 (3, 83)	.003	.16	.110

Note. Results with a significant Levene test are provisional pending Welch's F and Games-Howell comparisons.

4 Discussion

4.1 CPM adoption and training

Respondents rated adoption above the midpoint, and the difference was large. Agreement was strongest on the analytical value of CPM and weakest on training. This suggests that practitioners accept what CPM does more readily than their organizations invest in the skills to use it. The training result agrees with a Lagos study in which lack of scheduling expertise was among the three leading causes of delay from ineffective scheduling [5]. It also fits the technical literature, in which usefulness depends on the quality and currency of the schedule [10], [9]. Aredah et al. found that 51% of respondents most often used CPM among scheduling techniques [26]. That measure differs from agreement with statements about use, so the two cannot be compared directly, but they do not conflict. Two qualifications apply. Adoption was measured by what respondents say and not by inspection of schedules, and reported use and schedule quality can differ [10]. Social desirability may also raise the scores [20]. The score of 3.27 for preferring traditional methods suggests that some respondents work in organizations where CPM has not replaced them.

4.2 Delay factors

Several top-ranked factors agree with earlier work. Productivity of Nigerian tradespeople is limited by project-specific constraints [27], and bad weather appears among the underlying delay factors in Nigeria [28]. The weight given to design changes matches the leading place of design and contract document errors in Saudi capital projects [29], and the weight given to corruption and bureaucracy agrees with Nigerian studies [30], [6]. In CPM terms, low productivity lengthens activity durations, design changes alter logic and scope after the baseline is set, and weather and equipment constraints interrupt activities that have no float.

Two results differ from the literature. Finance ranked tenth here, at the midpoint, although earlier Lagos studies placed contractor finance or cash flow first or second [4], [5], [7]. Two explanations are possible. The instrument had no item on late payment or contractor cash flow, and the sample included clients, consultants and government agencies as well as contractors and was dominated by respondents on large projects in Eti-Osa. Poor planning and duration estimation also ranked low, whereas inaccurate estimation of contract duration ranked among the leading causes in Addis Ababa [31] and poor decisions on activity criticality ranked first in a Lagos expert study [5]. Respondents may attribute delay to external conditions, and estimation error is hard to see from inside a project, because classical tools give optimistic dates when durations vary [11]. This is a hypothesis the data cannot test, because the ranking was not broken down by type of organization.

4.3 Crashing and schedule recovery

Respondents judged crashing effective, and agreement was highest for overtime, extra manpower and alternative techniques. Agreement was lower that compression follows cost-benefit analysis, which is where reported practice departs most from the method in the literature. Ranking activities by crash slope and recalculating the network after each step are central to time–cost trade-off analysis [12], and recent models add that cost is not always linear in duration and that quality and contract terms matter [32], [13]. Without that analysis, extra resources may go to non-critical activities or cost more than the time they save. A second tension arises from the leading delay factor. Where skilled labour is scarce, adding crews may not be possible, and the effect of extra labour depends on productivity [33]. Resource limits also change which compression plan is best [34]. Respondents' agreement that cost and resource limits restrict crashing is consistent with this reading, which was not tested.

4.4 Relationships and group differences

The weak link between adoption and delay severity and the moderate link between delay severity and crashing effectiveness are most plausibly explained by exposure. Firms that suffer more delay may rely more on CPM and recovery techniques, so the associations may show where the tools are needed and not what they achieve. The lack of a link between adoption and crashing effectiveness suggests that using CPM does not by itself make recovery seem effective, which fits the view that recovery depends on network quality, duration accuracy, resources and decisions [10], [9]. Benchmarks for effect size are generous in some fields, and a correlation of .20 may already be meaningful [22], so the first two associations should not be dismissed. Builders rated crashing highest while reporting the lowest adoption. They may use acceleration measures on site without formal network scheduling, but the data do not test this. Because of the small groups, the dominance of Eti-Osa and the unequal variances, a Welch-based reanalysis with Games-Howell comparisons is needed [23], [24].

4.5 Proposed framework

Figure 2 organizes the supported strategies into six linked stages: (1) early planning with contractor, client and consultant input; (2) CPM network development using productivity and equipment records for durations; (3) monitoring with frequent delay analysis; (4) critical-path diagnosis, which checks whether a delayed activity is critical and whether the critical path has shifted; (5) a recovery decision that compares crash slopes and alternatives before committing resources; and (6) digital and institutional support. Each stage is tied to a finding. Early involvement scored highest (4.09), labour and equipment ranked first and fourth among delay factors, daily delay analysis ranked second (3.90), and agreement that compression follows cost-benefit analysis was only moderate (3.41). Stage 3 relies on frequent updating of progress data, which recent work shows can be assembled at activity level [35], and delay analysis techniques remain incomplete where float is consumed or the critical path shifts [36]. Stage 6 introduces BIM and learning-based tools in step with training, since both have been tested elsewhere [37]–[39] and the training score here was the lowest adoption item. The framework is derived from the survey and has not been tested on live projects.

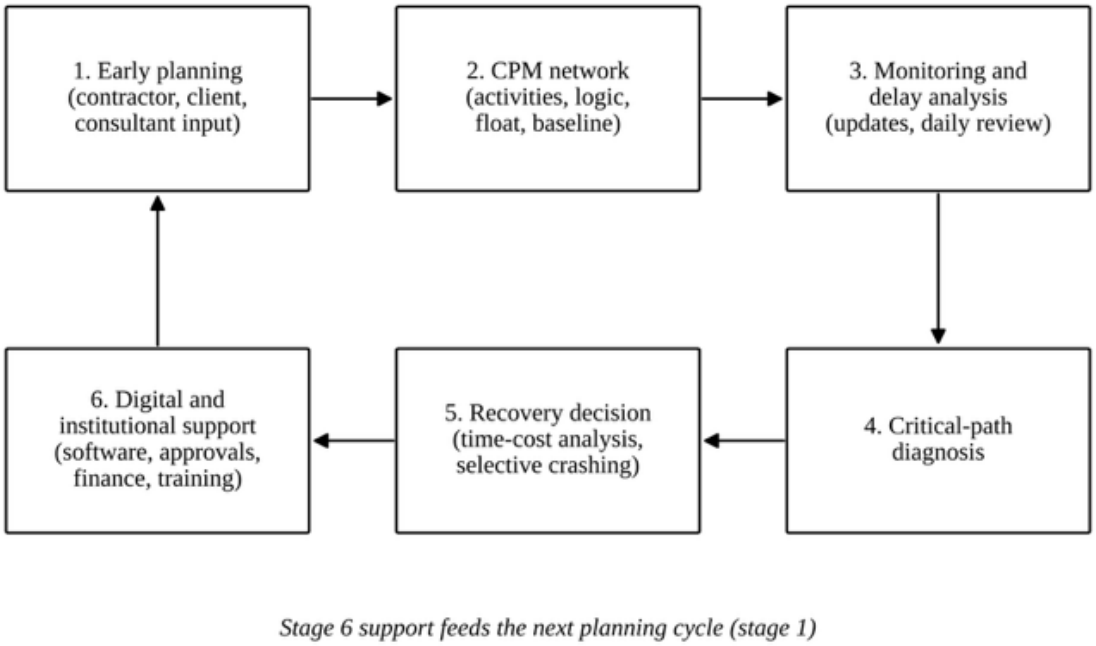


Figure 2. Proposed six-stage CPM-based framework for schedule improvement and delay mitigation (derived from the survey; not validated on live projects).

4.6 Limitations

The sample is non-probability, the response rate was 39.6%, and respondents concentrate in Eti-Osa (71.1%) and among contractors (55.2%). No quantity surveyors and only three architects responded, and Alimosho is not represented. All results are perceptions, adoption was measured by agreement with statements, several items combine two ideas, and the delay list omitted late payment and cash flow. The indices were computed from items as coded, and the reversed values are given as a sensitivity check. Group comparisons are underpowered and use the standard ANOVA where vari-

ances were unequal. A cross-sectional design cannot show change over time, and no schedules were analysed.

5 Conclusion

Lagos professionals in this sample report CPM adoption and perceived crashing effectiveness significantly above the scale midpoint, each with a large effect. Training is the weakest part of adoption, and cost-benefit analysis is the weakest part of crashing practice. Labour shortages and low productivity, bad weather, design changes, equipment constraints and governance issues are the leading influences on critical-path activities among the 16 listed. Perceived crashing effectiveness is unrelated to adoption, and early contractor involvement and frequent delay analysis are the most supported strategies. Finance and duration estimation ranked lower than in earlier Nigerian and Ethiopian studies.

The study contributes the first single-sample link, among the studies reviewed, between CPM adoption, critical-path delay factors, crashing perceptions and supported strategies in Lagos. It also states the identity between RII and the mean for five-point scales, reports effect sizes and confidence intervals, and tests the sensitivity of the indices to reverse scoring. Practical recommendations follow: structured CPM and software training, updating the baseline at set intervals, recording labour productivity on critical activities, change control that assesses each variation against the critical path, a time–cost comparison before crashing, and early contractor involvement. Future work should compare reported use with planned and actual schedules, add late payment and cash flow to the delay list, recompute the indices with negative items reversed, apply Welch-based tests to a larger sample covering all five LGAs, and validate the framework through expert review and live projects.

Declarations

Conflict of interest: The authors declare no conflict of interest.

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Author contributions: Y. L. Ogunsola: conceptualization, data curation, methodology, investigation, formal analysis, writing – original draft, writing – review and editing. A. K. Coker: conceptualization, resources, supervision, validation, writing – review and editing.

Data availability: The anonymized survey data are available from the corresponding author on reasonable request.

Ethics statement: Participation was voluntary and anonymous, with informed consent, as described in the Research ethics section.

Originality: This manuscript is original, is not under consideration elsewhere, and has not been published previously in any language. It is based on the first author's thesis for a postgraduate degree at the University of Ibadan.

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