LINEAR SCHEDULES QUALITY ASSESSMENT

A Framework for Construction Projects with Repetitive Activities

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Abstract. Construction projects are often criticized for over running time and cost. Previous studies often identified ineffective planning and scheduling as the most frequently cited cause of delay. Schedule development usually starts in the tendering stage of projects and gets further developed upon contract award to establish project baselines. They are subsequently used for planning work along with the required resource, progress monitoring and reporting, forecasting and determination of extension of times, if necessary, for completion. Problems that become apparent during the assessment of construction claims and disputes emphasizes the importance of producing high-quality baseline schedules. Several criteria have been identified to measure schedule quality through various initiatives and models. This study critically reviews existing schedule quality assessment models in the literature; outcomes of the review are used as the basis for interviews with industry professionals to identify potential areas for enhancement. There were 23 established criteria validated by questionnaire with 47 participants. Survey results indicated a high level of agreement with the defined criteria. These factors are ranked according to their relative importance. Rank correlations between owners, consultants, contractors and sub-contractors are then conducted to measure the degree of rank correlation between different parties. The results suggest that contractual measures are of the highest rank and duration estimation comes second. In addition, a high degree of ranking correlations between all parties is observed.

1. Introduction

Projects across many industries fail to deliver to expectations. The construction industry is often criticized for over running time and budget. Assaf and Al-Hejji (2006) found that 70% of studied projects in Saudi Arabia failed to finish on time. Ineffective planning and scheduling is ranked amongst the top causes of delay. Several studies reported that sources of ineffectiveness in construction planning and scheduling are attributable to high complexity, uncertainty, scheduling techniques, scheduling practices and the dynamic nature of construction projects (Emam and Farrell, 2014). Construction schedule quality should be assessed based on their expected functionalities that can be defined as: planning works along with associated resource, monitoring progress, reporting, forecasting and determination of extension of time for completion. High-quality schedules should be fit for purpose and robust.

Schedule quality review has been investigated in the literature, with a focus upon technical baseline schedules and forensic schedules analysis methods. Schedule quality review studies have been concentrating on network-based schedules that were criticized for not being an appropriate method to model projects with repetitive activities (Galloway, 2005). On the other hand, linear schedules are considered more suitable to model projects with repeating activities. Linear scheduling method is a two-dimensions scheduling where, time and distance are plotted on perpendicular axis and tasks are represented by diagonal lines and their slope is the rate of progress (Johnston, 1981). Linear schedule reviews do not receive a lot of attention in earlier studies. Hence, this study mainly contributes to present factors affecting linear schedules quality and feasibility. The paper is structured to commence with a brief explanation of methodologies used followed by a literature review to investigate attempts of earlier studies; results are presented and used as the subject of discussion in later sections. The conclusions include proposals for future research.

2. Literature Review

The importance of quality schedules received considerable attention from governments, researchers and industry experts. These efforts can be categorized into standards/guides for schedule evaluation; automating schedules review processes and quantitative schedules quality measurement. In this section, publications related to the context of this study are highlighted.

Schedule quality evaluation literature is focused on schedule development and baseline reviews. Professional bodies such as the Project Management

Institute (PMI) established practice standards for scheduling (PMI, 2007) that concentrated on baseline schedule development, while the Association for Advancement of Cost Engineering (AACE) introduced various professional recommended practice guides such as schedule update reviews (Winter, 2008). The Chartered Institute of Building (CIOB, 2011) developed a good practice guide for time management which provides generic guidance for schedule review and emphasizes the importance of dynamic scheduling.

On the other hand, government organizations contributed to baseline schedule development and assessment through several initiatives. The US Defense Contract Management Agency (DCMA) identified a 14-point assessment method for baseline and updated schedules (Berg *et al.* 2009). The identified 14 points are: logic, leads, lags, relationship types, hard constraints, high float, negative float, high duration, invalid dates, resource, missed tasks, critical path test, critical path length index (CPLI), and the baseline execution index (BEI). DCMA’s approach ignored crucial criteria for schedule review and assessment such as contractual compliance, risk analysis and activity durations. However, also in the US, the Government Accountability Office (GAO, 2012) developed the ‘GAO Schedule Assessment Guide’ that improved DCMA’s model by including additional criteria such as schedule risk analysis, resource leveling, dangling logic, and resource constraints. The GAO guide included ten best practice items for schedule evaluation thus: capturing all activities, sequencing all activities, assigning resources to all activities, establishing the duration of all activities, verifying that the schedule can be traced horizontally and vertically, confirming that the critical path is valid, ensuring reasonable total float, conducting a schedule risk analysis, updating the schedule using actual progress and logic, and maintaining a baseline schedule. The National Defense Industrial Association (NDIA, 2012) introduced the Planning and Scheduling Excellence Guide (PASEG).

Automating schedule reviews has been the subject of various studies. De La Garza and Ibbs (1990) investigated schedules review of mid-rise buildings through a computerized system called *CRITEX*. The system assessed schedules based on thirty-four defined criteria obtained from interviews with schedulers. *CRITEX* was criticized for not proposing remedies for schedule revision (Dzeng and Lee, 2004). *ScheduleCoach* was designed to overcome shortfalls of the previous *CRITEX* system by introducing suggested revision to schedules in addition to comments on possible errors. Dzeng and Lee (2004) developed a knowledge-based system using used rule-base and case-based reasoning approaches to identify potential errors and recommend remedies. Meanwhile, *ScheduleCoach* limited schedule analysis to predefined standard activities. Dzeng *et al.* (2005) established Network Review Assistance (NRA) system; an automated schedule assessment system for expressway construction projects. The NRA system reviewed network-based schedules. However, the network-based approach was criticized for being an inefficient scheduling process for projects with repetitive activities (Galloway, 2005). Moosavi and Moselhi (2014) tried to overcome shortfalls of previously identified systems by identifying 48 schedule quality criteria, grouped under obligatory and complementary categories. These criteria were then assigned weightings and used to establish the schedule development index (SDI). This index is used to measure schedule fitness for purpose. The SDI calculation was then programmed in an automated system for schedule review.

Various attempts to establish rigorous quantitative measures for schedule quality have been made; with focus on schedule complexity (Badiru and Pulat, 1995). Nassar and Hegab (2006) introduced new measurement criteria that consider complexities in different contexts but results showed schedules with more links are considered more complex in general. Khan and Siddiqui (2010) argued that complexity is not necessarily a measure of quality and they defined schedule quality as the ability to absorb project delays. They proposed value centrality and path centrality as two measures to assess schedule quality based on the aforesaid definition; using directed acyclic graph theory. Established criteria ignored crucial elements that might affect schedules feasibility, such as resource constraints and uncertainties. Furthermore, there were no criteria developed to assess schedule quality of projects with repeating activities; that is known as the linear scheduling method.

3. Methodology

This study involves a literature review to identify factors affecting linear schedule quality. An in-depth literature review was conducted to identify scheduling purposes, and quality assessment criteria were established. The survey included industry standards, journal articles, conference papers, books and industry best practices. Defined quality criteria were checked to ensure their measurability. After the outcome of the literature review, the analysis was piloted on planning and scheduling practitioners. Planners were asked to comment on the relevance of identified criteria and propose additional relevant measures that were not considered. The defined 23 factors were then categorized under six groups. These factors were used to develop a questionnaire to quantity their relative importance.

3.1 SURVEY DESIGN

Defined criteria were organized in a survey that was categorized in two groups of questions. The first group was used to collect professional data on participants such as areas of expertise, relevant experience, current position within their organizations, and size of projects in which they are involved. In addition, questions were added to capture the degree of knowledge about linear scheduling, relevance of using linear schedules in projects with repeating activities, and the extent to which linear schedules are utilized within their projects. Interview results identified six uses of linear scheduling these are: preparing project baselines, reporting progress, detecting time-location clashes, what-if scenario analysis, resource requirements and leveling, and communicating schedules to stakeholders. The extent of employing linear scheduling in each of the aforesaid uses was measured on a five-point Likert type scale: no usage, little usage, moderate usage, strong usage, and extensive usage.

The second part of the survey investigated the importance of each of the identified factors. These were organized in six groups; these are schedule parameters, logic, constraints, durations, resource, and contractual compliance.

Participants were asked to identify the level of importance for 23 possible factors contributing to linear schedules quality on five-point Likert scale as follows: (0 = unimportant, 1 = of little importance, 2 = moderately important, 3 = important and 4 = very important). Participants were asked to add any additional factors or remarks at the end of the questionnaire. Sample size is important for to obtain representative results. The population of this study includes construction planners that work in projects with repetitive activities. Since it is very difficult to estimate population size, the most widely used rule of thumb was employed for the sample size which is getting the maximum size possible within affordability constraints, as argued by Olejnik (1984). There were 47 planning practitioners from owners, consultants, contractors, and sub-contractors organizations participated in the survey, and their distribution is shown in Table 1.

Table 1 Distribution of participants

Participant Categories	**Number**	**Percentage**
Client/Owner	5	10.64%
Consultant/Designer	13	27.66%
Main Contractor	25	53.19%
Sub-Contractor	4	8.51%
Total	47	100%

3.2 DATA ANALYSIS

The collected data were analyzed using various statistical tools. This section discusses statistical methods applied to analyze survey results. These methods are used to rank criteria and measure correlation between different groups.

3.2.1 Ranking

Relative importance index for each of the factors was calculated. These indices were used to rank factors based on their importance. The method for calculating importance indices is shown in formula 1.

$$\text{RII} = \frac{\sum W x_i}{An} \quad (1)$$

where W is the weight assigned to each factor by participants and ranges from 0 to 4 where '0' is ‘unimportant' and '4' is 'very important'; x is the frequency of the ith response; A is the highest possible weight for response which is 4 in this particular case; and n is the total number of responses.

3.2.2 Internal reliability test

Cronbach's alpha test is a tool to measure internal reliability and consistency. A high Cronbach’s alpha implies that items measured are reliable but does not mean uni-dimensional. Cronbach’s alpha is computed as follows:

$$\alpha = \frac{k}{\text{k}-1}\left(1 - \frac{\sum_{j=1}^{k} \sigma_{u_j}^2}{\sigma_x^2}\right) \quad (2)$$

Where k is the number of questions in the survey; $\sigma_{\text{u}_\text{j}}^2$ is the variance of scores on each question; and σ_x^2 is the total variance of overall scores.

3.2.3 Spearman’s rank correlation

Spearman’s rank correlation is a statistical non-parametric test that compares degrees of agreement between two groups on ranking. Since the method can compare correlation between two groups, rank correlation is measured between two groups without considering other groups. This method was selected due to its advantage of not requiring assumption of homogeneity and normality. Spearman’s rank correlation is calculated using the following equation:

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where r_s is Spearman's rank correlation coefficient; d is the difference in ranking between two groups; N is the number of variables (groups).

4. Results

Despite there being no studies in the literature that directly investigate linear schedules quality assessment; several criteria were determined by reading related studies. Initially, identified factors affecting schedule quality exceeded 120. These were filtered by removal of measures that are only applicable on network-based schedules review and not to linear schedules. The filtering process resulted in 23 factors categorized into six groups that contribute to linear schedules quality as listed in Table 2.

The defined criteria were piloted to construction practitioners to obtain their feedback. Practitioners were asked to comment on the relevancy of criteria identified and additional measures thought to be of high importance. The feedback received from interviews indicated that Location Breakdown Structure (LBS) should be included rather than traditional Work Breakdown Structure (WBS) that is often used in activity-based schedules. Interviewees also suggested that in addition to validating the scope inclusion, LBS should be organized in a hierarchy. Hierarchal structure allows summarizing schedules for different purposes such as optimizing construction sequences on a high level, and planning details and finishes on lower levels. Proper LBS were often combined during discussions with the ability to produce schedules with the high presentation quality that is argued to be the power of location-based schedules. It was proposed to add unique task identification references that describe several factors as locations and types of work. Moreover, tasks measurability criterion was emphasized to enable adequate progress tracking and monitoring. Special attention to schedule assumptions and narratives were observed during interviews by cross referencing these documents while discussing resources, durations and interfaces.

TABLE 2. Linear schedules review criteria.

Group	Description
Schedule Parameters	Location Breakdown Structure (LBS) covers full project scope Clarity and uniqueness of task descriptions Tasks must be measurable Quantitative schedule risk analysis Presentation is clear, organized and understandable Schedule and narratives are compliant
Logic	Open ends not allowed (except for project start and finish) Open starts and open finish (SS or FF without finish or start relationship) Logic density Redundant logic
Constraints	Mandatory constraints are not allowed Soft constraints usage shall be minimized
Durations	Durations are calculated based on quantities of work and resource assigned Variations in durations are considered due to variability of location Variations in durations are considered due to change in weather
Resource	All tasks are resource loaded All tasks shall be cost loaded Resource constraints are considered, and no violations detected Resource leveling is implemented, and variations are minimized
Contractual	All contractual interfaces are clearly defined Calendars must comply with laws and regulations Contractual milestones are all included in the schedule Logic enforced by contract must be applied

The logic section was agreeable amongst interviewees; they acknowledged importance robust logic to achieve schedule goals. The emphasis was on hidden logic failure as called by interviewees, describing ‘open starts’ and ‘open finishes’ rather than ‘open ends’. Differences were identified as open ends activities without a predecessor or successor. On the other hand, open starts activities linked with a finish-to-finish relationship without linking its start as shown in figure 1. The same concept applies to using mandatory constraints where participants urged to avoid using such constraints due to disruptions caused to schedule calculations.

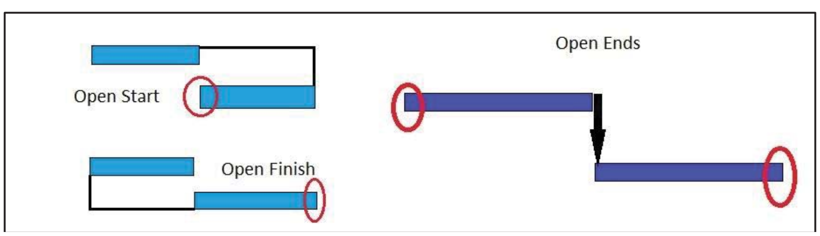

Figure 1: Comparison of Open Logic

Accurate and reliable duration estimation is of considerable importance to achieving schedule targets. Interview results demonstrated several factors affecting precise estimation of durations; these factors are productivity rates, preparatory investigations, and preceding activities progress rate.

Productivity rates are sensitive to several factors such as workspace limitations, unforeseen conditions and weather. An example of space limitation would be excavating soil; allocating large numbers of excavators on sites with limited area will restrict movement and drop the productivity of all equipment. Meanwhile, weather conditions considerably affect productivity in winter for countries with cold weather and summer in hot countries. Unforeseen conditions are of higher impact on horizontal linear projects than vertical due to extending over large areas. These conditions can be unforeseen ground conditions, or underground utilities that need diversion.

Resource can be scarce and crucial to accomplish construction tasks. Proper resource should be available to ensure achieving planned works. Two main measurement criteria were considered in schedule quality assessments; these are assignment and availability. Resource assignments include labor, equipment, material and cost. These resource assignments allow reviewing requirements to achieve schedules. Meanwhile, feasibility is a follow on phase where resource availability, and leveling are reviewed along with associated constraints to ensure the feasibility of schedules.

Contractual requirements are mandatory to comply with obligations. These elements are depicted in quality assessment by means of accounting for interfaces, compliance with laws and regulations, milestone dates and logic driven by contracts. Deviating from the aforementioned conditions is considered as a breach in contracts.

4.1 CRITERIA RANKING

Collected survey data were used to rank quality criteria defined earlier. The ranking was carried out based on relative importance index (RII). Calculations were made for each factor based on gathered data from questionnaire participants, and results are shown in Table 3. It is noticed that contractual requirements were placed on top of the list. On the other hand, redundant logic and soft constraints came at the bottom of the list. That is attributable to the fact that redundant logic increases complexity of schedules but does not affect baseline calculations; the same applies to soft constraints. It is observed that using hard logic also came as a lower rank while these types of constraints affect schedule calculations and cause interruptions to the overall network.

TABLE 3. Ranking schedule quality factors

Rank	Description	RII
1	Contractual milestones are all included	0.910
2	All contractual interfaces are clearly defined	0.899
3	Logic enforced by contract must be applied	0.888
4	Duration is calculated based on quantities of work and resource assigned	0.867
5	Open ends not allowed (except for project start and finish)	0.851
6	Location Breakdown Structure (LBS) covers full project scope	0.846
6	Calendars must comply with laws and regulations	0.846
8	Tasks must be measurable	0.840
9	All tasks are resource loaded	0.830
10	Variations in duration due to location conditions are considered	0.814
11	Clear Presentation	0.809
12	Clarity and uniqueness of tasks description	0.782
13	Schedule development in compliance with the narrative	0.771
14	Resource leveling is implemented, and variations are minimized	0.745
15	Logic density	0.734
16	Variations in duration due to change in weather are considered	0.718
17	Resource constraints are considered, and no violations detected	0.713
18	All tasks are cost loaded	0.707
19	Quantitative schedule risk analysis	0.676
20	Open starts and open finishes	0.670
21	Mandatory constraints are not allowed	0.660
21	Soft constraints usage shall be minimized	0.660
23	Redundant logic	0.559

In addition to ordering individual factors importance, groups of criteria were also ranked. The groups ranking results show ranking that matches individual factors ranking. Contractual factors came on the first rank followed by durations estimation, schedule parameters, resource requirements, logic and constraints usage as shown in Table 4.

TABLE 4. Groups Ranking

Rank	Description	Score
1	Contractual	0.885
2	Durations	0.802
3	Schedule Parameters	0.791
4	Resource	0.764
5	Logic	0.706
6	Constraints	0.674

4.2 GROUPS RANKING BY ORGANIZATION TYPES

Ranking is performed by considering separate groups in order to provide more insights on perceptions by different groups as illustrated in Table 5. It is noticed that contractors and sub-contractors rankings are identical.

TABLE 5. Ranking of groups by organization type

	Owner		Consultant		Contractor		Sub-Contractor	
Group Description	**Score**	**Rank**	**Score**	**Rank**	**Score**	**Rank**	**Score**	**Rank**
Contractual	0.788	2	0.865	1	0.918	1	0.875	1
Durations	0.817	1	0.763	3	0.820	2	0.771	2
Schedule Parameters	0.775	3	0.795	2	0.797	3	0.719	3
Resource	0.738	4	0.716	4	0.775	4	0.703	4
Logic	0.638	5	0.654	6	0.748	5	0.672	5
Constraints	0.550	6	0.673	5	0.675	6	0.656	6

4.3 INTERNAL RELIABILITY

The questionnaire internal consistency and reliability is calculated using Cronbach's alpha; the computed coefficient value is 0.792. The coefficient value is considered acceptable as it is greater than a benchmark of 0.70 (Nunnally and Bernstein, 1994).

4.4 RANK CORRELATION

The groups rank correlation is tested using Spearman’s correlation coefficient. Results suggest high correlation coefficients between parties with the exception contractors and sub-contractors that had a correlation coefficient value of 1.0, which suggests a perfect correlation.

Table 6. Spearman's rank correlation factors

Parties	**Spearman Correlation Coefficient**	**Significance Level**
Owner and Consultant	0.771	0.05
Owner and Contractor	0.943	0.05
Owner and Sub-contractor	0.943	0.05
Consultant and Contractor	0.886	0.05
Consultant and Sub-contractor	0.886	0.05
Contractor and Sub-contractor	1.000	0.05

5. Discussion

This section presents results discussion and elaboration. The ranking of criteria reveals an interesting focus on contractual obligations. This was noticed by having the top three criteria in rank related to contracts, thus: contractual milestones are all included, all contractual interfaces are clearly defined, and logic enforced by contract must be applied as reported in Table 3. In addition, group ranking of criteria supported the aforesaid observation and reported contractual group as the top ranked as in Table 4. These results are in agreement with Moosavi and Moselhi (2014) acknowledgement on the importance of contractual compliance within schedules. The durations group is reported as the second most important. The high ranking of the group is due to its direct relation to developing an achievable and realistic schedule. The lack of such realistic schedule is cited as one of the most frequent causes of project delays as concluded by Assaf and Al-Hejji (2006). Schedule parameters are ranked in the third place of importance with six criteria that covers schedule scope and clarity. These are important factors that facilitate schedules communication with various stakeholders (CIOB, 2011). The fourth group in importance is the resource that included assignment to tasks, leveling and resources constraints satisfaction. The resource assignment is broken-down to monetary (ranked in the 18th place) and non-monetary resource (Ranked as the 9$^{th)}$ i.e. materials, equipment and labors. The ranking of resource assignment seems to be sound due to the considerable importance of non-monetary resource to schedule feasibility and constructability. This is supported by the work of Smith (2005). Logic and Constraints groups were ranked late due to practitioners perception on linear schedules; they are thought to be a graphical representation of schedules without real scheduling calculation similar to CPM. Whilst this perception is incorrect, one of the major advantages of LSM is the visualization and simplicity of understanding schedules.

Group ranking by organization type had some differences; this is expected due to different priorities of organizations. Contractual requirements ranked first amongst stakeholders except owners. Owners identified priority being durations. This variation propose that owners are more concerned about project completion deadlines and achieving targets than fulfilling contractual obligation in schedules. On the other hand, consultants and contractors believe that satisfying contracts requirements will lead to successful completion of project. In general, the results suggest a high level of ranks agreement through different organization types ranging from 0.77 to 1.0. The high rank agreement between parties supports the reliability of the results and the subsequent analysis. Internal reliability was statistically tested by Cronbach's alpha that demonstrated a high level of reliability of 0.792.

6. Conclusion

This study established initial criteria for reviewing and assessing linear schedules. These criteria were identified from the literature and introduced to professional planners in interviews to get their opinions. The literature review and subsequent interviews resulted in filtering twenty-three factors that contribute to linear schedule quality. The schedules quality assessment criteria were ranked using a relative importance index that was computed using data obtained from an on-line questionnaire. The survey collected data from forty-seven professional construction planners. Further statistical tests were applied to the survey data to ensure its reliability and to test the correlation among different groups. The reliability test demonstrated a good level of reliability that gives confidence in survey data. Rank correlation analysis was also conducted using Spearman's correlation coefficient, results showed high correlation factors between various parties with an exception to contractors and sub-contractors that had a perfect correlation coefficient.

It is recommended that future studies with larger sample size to confirm results of this research should be conducted. The development of an index for measuring the quality of linear construction schedules is a possible research topic that can be used as a unified measure to allow comparisons is a potential research area. In addition to the aforementioned index, an automated system for assessing linear schedule quality using the earlier described index is a probable area for future research.

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