Case Study

Review of Detailed Schedules in Building Construction

S. Farzad Moosavi[1] and Osama Moselhi, F.ASCE[2]

Abstract: Detailed schedules are essential in the development of project baselines; they are needed for tracking and progress reporting, as well as for the administration of construction disputes. Thus, it is necessary to ensure the fitness for purpose of these schedules. Presented in this paper is a structured method to assist owners or their agents in reviewing and evaluating detailed schedules submitted by contractors. The method is developed making use of related knowledge extracted from the literature and augmented by expert opinions gathered from an online questionnaire survey and structured interviews. A composite index is introduced to evaluate the overall level of schedules' fitness for purpose, taking into account the level of importance of each evaluation criterion. The method was implemented in a software application to facilitate its use. Schedules of three actual and one hypothetical projects are analyzed to demonstrate the essential features of the developed method and to highlight its capabilities. In addition, an empirical method is developed to review job logic, making use of in-depth analysis of the data collected from the schedules of three building construction projects. **DOI: 10.1061/(ASCE)LA.1943-4170.0000142.**

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Introduction

Detailed construction schedules are frequently developed by contractors upon the award of contracts and submitted to owners for approval. The approved schedules (project baselines) are needed for project execution, tracking, and progress reporting. Moreover, they provide the legal basis for the administration of construction disputes and claims. Therefore, it is imperative to ensure the fitness of these schedules for their intended purposes. Owners or their agents review and evaluate these schedules based on a number of considerations, which are usually subjective and vary from one organization to another. The study presented here reveals that, in view of the sporadic knowledge in this domain, some of these considerations are overlooked in schedule review methods used in current practice.

De La Garza and Ibbs (1990) introduced a computer system, *CRITEX*, for critiquing schedules of midrise commercial construction. Their system encompasses 34 generic schedule review provisions. Nevertheless, assessments of schedule job logic and activity durations were not addressed adequately because the defined criteria were too generic. For example, the following rule was stated in De La Garza and Ibbs (1990): "Activities sequencing and interdependencies should represent a reasonable plan for accomplishing the work." Subsequently, Dzeng and Lee (2004) developed for the same purpose a knowledge-based system, *ScheduleCoach*, utilizing rules-based and case-based reasoning. Dzeng and Lee (2004) stated that *ScheduleCoach* is restricted to schedules developed using a single set of standard activities.

There have been a few guides developed by U.S. government agencies, including the Government Accountability Office (GAO) and the Industrial Committee for Program Management (ICPM) of the National Defense Industrial Association (NDIA). These agencies developed guides called the *GAO Cost Estimating And Assessment Guide* (GAO 2009) and *Planning and Scheduling Excellence Guide (PASEG)* (NDIA-ICPM 2011). These guides introduced a set of schedule development recommended practices. The guides, although useful, are generic and do not provide an adequate level of detail. For example, in GAO (2009) and NDIA (2011) the following rules were stated respectively:

"The duration of each activity must be estimated, usually with reference to the resources assigned for its execution and any external factors affecting its duration" and the schedules should provide "meaningful critical paths and accurate forecasts for remaining work through program completion."

This renders them of limited relevance in the direct assessment of schedules. In addition, the guides focus merely on the schedule as a product and overlook the process of schedule development despite its significant impacts on schedule fitness for purpose (Moosavi and Moselhi 2012). Furthermore, the U.S. Defense Contract Management Agency (DCMA) developed a method, DCMA 14-Point Assessment, to evaluate Integrated Master Schedules (Berg et al. 2009). This method encompasses 14 tests for the health assessment of initial and in-progress schedules and does not consider important issues such as contractual compliance, reasonability of job logic, and activity durations.

An in-depth review of the literature cited earlier indicates that, in addition to the limitations noted, there are two main deficiencies: there is no consideration of the different levels of importance of criteria items and there is inadequate support for owners as to when to consider a schedule acceptable or unacceptable.

This paper presents a structured method to assist owners in performing an objective review and effective schedule assessment and evaluation. It detects acceptable and unacceptable schedules and ranks acceptable schedules based on their measured degree of fitness for purpose. A composite index is proposed for the assessment of the overall level of fitness for purpose of detailed

[1]Graduate Student, Dept. of Building, Civil and Environmental Engineering, Concordia Univ., 1455 Blvd. de Maisonneuve W., Montreal, QC, Canada H3G 1M8 (corresponding author). E-mail: s.farzadmoosavi@gmail.com

[2]Professor, Dept. of Building, Civil and Environmental Engineering, Concordia Univ., 1455 Blvd. de Maisonneuve W., Montreal, QC, Canada H3G 1M8. E-mail: moselhi@encs.concordia.ca

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schedules, taking into account the relative level of importance of each criterion used in the developed index. In addition, an empirical method is presented for the job logic review of schedules that are developed for the construction of multistory institutional buildings.

Developed Method

The initial development work of this research began with a comprehensive literature review to define and establish appropriate criteria for schedule assessment and evaluation. This included input from three sources: (1) textbooks and dissertations, (2) journal articles and conference proceedings, and (3) recommended practices and guides developed by professional organizations and government agencies. The criteria presented here are not intended to be exhaustive; rather, the intention was to avoid trivial criteria and incorporate frequently disregarded criteria in terms of clarity and practicality. Following a careful examination and review of the literature, an initial draft of 67 provisions was prepared with the aim of refining and clustering them in the next step (Moosavi 2012). To ensure that the defined criteria are to the point, practical, and clear to construction professionals, 20 sessions of structured interviews were conducted (Moosavi 2012). The results led to the use of 48 schedule assessment criteria, clustered as shown in Fig. 1. The defined criteria assess schedules from different perspectives including:

1. Contractual compliance: schedules must be in line with related contracts;
2. Completeness: schedules must thoroughly cover the scope of the contract;
3. Reasonableness of job logic: schedule job logic should be reasonable;
4. Realistic activity durations: activity durations should be in line with the scope of work, number of crews assigned, and their respective productivities;
5. Representativeness: schedules should represent the way projects are going to be constructed; and
6. Health: schedules must be healthy (e.g., free from open-ended activities, negative float).

The defined criteria were grouped into two major categories: (1) obligatory and (2) complementary. Each schedule must satisfy the obligatory criteria of contractual compliance, acceptable job logic (respecting the sequence of construction tasks), and reasonable activity duration (accounting for scope of work and productivity of crews involved). A schedule that does not satisfy any of these criteria is considered failed or unacceptable. The complementary category encompasses recommended criteria for consideration while reviewing schedules. Thus, if a schedule is able to satisfy the obligatory criteria, the evaluation process continues, using the complementary criteria, to examine to what degree it satisfies its fitness for purpose. A detailed description of the criteria and its construction can be found in Moosavi (2012).

Obligatory Criteria

1.1 Contractual Compliance
1. Milestones and Project Duration
2. Phasing and Sequencing
3. Number of Activities
4. Activity Code
5. Schedule Submission Date
6. Scope Coverage

1.2 Job Logic
7. Job Logic

1.3 Duration
8. Activity Duration (reasonability)

Complementary Criteria

2.1 Schedule Development
2.1.1 Scope
9. Project Scope Definition
10. WBS Verification

2.1.2 Process
11. Scheduling Process
12. Subcontractor Participation
13. Verification of Subcontractor Scope of Work

2.2 Schedule Components
2.2.1 Overview
14. Verification of Project Duration
15. Minimum Milestones
16. Verification of Project Performance
17. Phase Duration
18. Phase Overlaps
19. Calendar Verification
20. Working Hours Schedule-Estimate Compliance
21. Congestion Index

2.2.2 Critical Path
22. Schedule Criticality Rate
23. Near Criticality Rate
24. Project Effort Ratio
25. Project Cost Ratio
26. Critical Activity Affiliation
27. Critical Activity Duration

2.2.3 Resources
28. Resource Loading
29. Responsibility Assignment
30. Schedule Leveling
31. Trade Peak Resource Loading
32. Trade Peak Resource Loading relation
33. Trade Rate of Completion per Week
34. Peak to Average Labor Ratio

2.2.4 Special Considerations
35. Permits and Environmental Remediation
36. Startup and Testing Activities
37. Submittal Activities
38. Submittal Review Activities
39. Procurement Activities

2.2.5 Activity attributes
40. Number of Activities
41. Total Float
42. Negative Total Float
43. Weather-Sensitive Activities
44. Activity Duration (Rules of Thumb)
45. Number of Constraints
46. Lag
47. Relationship Ratio
48. Open-Ended Activity

Fig. 1. Defined criteria

The items, also referred to as provisions, of the criteria are not of equal importance; provisions deemed more important are assigned higher relative weights in comparison to others. To establish the level of importance of each criterion and its related weight, this research adopted the methodology used to weight Project Definition Rating Index (PDRI) elements for industrial projects (Bingham 2010), for building projects (Cho 2000), and for infrastructure projects (Construction Industry Institute 1996).

The relative weights in the developed method were determined based on feedback from professionals in the construction industry using an online questionnaire. Fifty-seven e-mails were sent, inviting participants to respond to the questionnaire posted on the World Wide Web. Professionals were requested to indicate the level of importance of each criterion on a scale of 1 to 10, where 1 represented "not important at all" and 10 stood for "extremely important." The questionnaire was kept on the Web for 5 months. Twenty-eight responses were received from project managers, planners, schedulers, and project control engineers in North America, resulting in a response rate of 49% (Moosavi 2012). The participants' professional working experience ranged from 4 to 28 years, with an average of more than 14 years (Fig. 2).

To calculate the weights of the provisions, each response was coded and entered into an Excel worksheet for further analysis. Only complementary criteria were weighed to measure the degree to which schedules, which satisfy the obligatory criteria, were in compliance with the complementary criteria. The weight of each criterion was calculated as the mean of the responses received. The calculated weights were then normalized to 1,000 for a "perfect" schedule, which completely satisfies the defined criteria. The Schedule Development Index (SDI), which represents a schedule's fitness for purpose, is calculated as the sum of the weights of the provisions that the schedule satisfies (Moosavi 2012).

Once the weights were calculated, the defined criteria were sorted in order of importance. The most important criterion was found to be P.11 scheduling process, which recommends the involvement of different participants in the scheduling process. This provision aims at minimizing different expectations between owners and their agents on one side and contractors on the other and providing common understanding and awareness among the stakeholders of the schedule characteristics and constraints, which can help mitigate in the long term delays and damages. The second most important criterion was P.15 minimum milestones, which requires that each schedule have start and end milestones [Project Management Institute (PMI) 2007]. This criterion aims at a clear demonstration of the start and finish dates of each schedule. The next ranked provision was P.39 procurement activities, which requires such activities to be succeeded by related installation tasks (De La Garza 1988). This provision aims to highlight the consequences of delays in procurement on construction and on the project completion date. P.10 WBS verification was found to be the next most important criterion. It requires that the scheduling process be based on an approved work breakdown structure (WBS). This requirement aims to ensure that schedules are developed based on agreed-upon project configuration and common understanding among project stakeholders. This criterion also represents one of the requirements of the Project Management Body of Knowledge requiring the existence of a WBS for each project (PMI 2007). The next key criterion was P.13 verification of subcontractors' scope of work. This urges schedulers to clearly show the start and completion dates of the trade contractors involved (Douglas 2009; De La Garza 1988). A list of the 10 most important criteria in descending order is depicted in Table 1. A detailed description of the evaluation criteria and their weights can be found in Moosavi (2012).

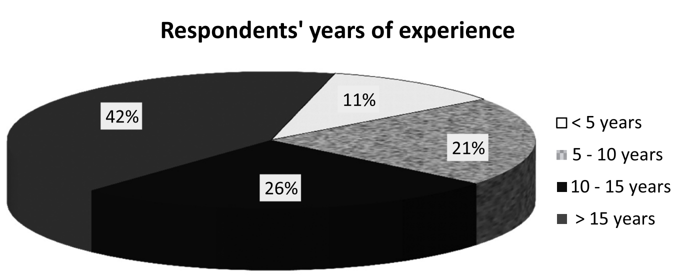

Fig. 2. Respondents' working experience

Table 1. Top 10 Schedule Assessment Criteria

Number	Criterion	Weight
1-1	P.11 Scheduling process	30
2-1	P.15 Minimum milestones	29
2-2	P.39 Procurement activities	29
3-1	P.10 WBS verification	28
3-2	P.13 Verification of subcontractors' scope of work	28
3-3	P.20 Working hours schedule-estimate compliance	28
3-4	P.22 Critical path	28
3-5	P.36 Startup and testing activities	28
3-6	P.37 Submittal activities	28
3-7	P.46 Negative total float	28

Empirical Method of Job Logic Review

A set of rules was developed to provide precedence relationships among common activities in building construction based on an in-depth analysis of three schedules of multistory building projects. These rules provide the basis for job logic review of schedules. The analysis was carried out using the as-planned and as-built data of these projects, where two were finished on time and the third was delayed 3 months beyond its 15-month planned duration (Moosavi 2012). The three projects are reinforced concrete structures constructed as educational buildings. The net area of these projects ranged from 6,000 to 68,000 m^2 (Moosavi 2012). The schedules of the three projects were examined closely, with a focus on activity relationships among eight major trades. The duration of each trade was extracted as a percentage of total project duration. Furthermore, the lags between these trades were extracted as a percentage of predecessor trade duration. The extracted data were analyzed and statistical analysis conducted on it. Table 2 presents a sample of the type of data collected and processed to generate precedence relationships among project activities. Although it is a limited project sample size, the relative proportions were similar in three cases (Moosavi 2012).

The findings of the analysis were then used to develop a typical schedule that could be used for empirical assessment of schedules of reinforced concrete educational buildings (Fig. 3); schedules could be compared to the generated schedule in the evaluation process. According to the default values embedded in the developed method, if there is any significant difference between duration or start time of the same trade, the method recommends further investigation (i.e., examining the number and formation of crews assigned or the technology used in relation to the scope of work) (Moosavi 2012). The results of the analysis were then transformed into a set of rules (i.e., rules of thumb). The results and the defined rules were presented to an experienced project manager in charge of the three projects considered in this study, referred to later as expert,

Table 2. Sample Results of Analysis of Schedules

Trade	Activity	Case A (%)	Case B (%)	Case C (%)	Average (%)	Variance	Predecessor	Lag	Lag range (%)
Foundation	Start	12	12	18	14	0.001	Excavation	FS-14%	−27
	Duration	3	3	2	3	0.000			—
	Finish	15	15	20	17	0.001			−15

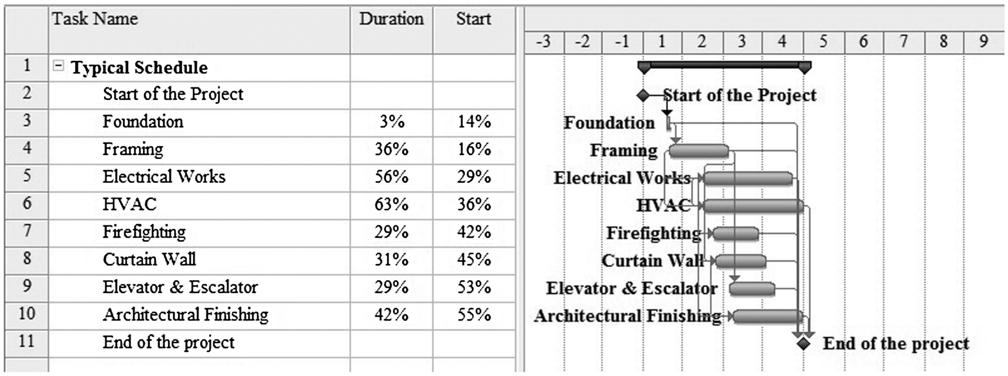

Fig. 3. Typical schedule for construction of institutional buildings

to elicit his feedback on the developed method and the defined rules through a structured interview (Moosavi 2012). The interview revealed general agreement between the expert's assessments and those generated by the developed methods; except for the overlaps between foundation and framing trade, between framing and curtain wall trade, and, finally, between framing and HVAC trade. Analysis of the three cases showed that the framing trade was started when the foundation was 70% complete. Also, the curtain wall trade was started when framing of five floors was completed, and the HVAC trade was started when framing was 55% complete. The expert stated that the successor trades could start sooner (i.e., using larger overlaps) and that typically when foundation is 30% complete framing can start. He also added that the HVAC trade could start when framing was 30% complete and the curtain wall trade could start when the framing of three floors was done. The final result was a set of rules for the assessment of the job logic of schedules developed for educational building construction (Table 3). Application of these rules helps users to quickly gain an

Table 3. Empirical Rules of Job Logic Assessment of Educational Buildings

Number	Rules
1	Duration of foundation trade is approximately 5% of framing trade duration
2	Typically, when more than 30% of foundation is complete, framing trade can start
3	Duration of framing trade is approximately 35% of project duration
4	Typically once framing of three floors is performed, curtain wall trade could start
5	Duration of curtain wall trade is approximately 30% of project duration
6	Typically once 30% of curtain wall is complete, architectural trade starts
7	Duration of architectural trade is approximately 40% of project duration
8	Typically, HVAC and electrical trades could start at the same time once 30% of framing is complete
9	Duration of electrical trade is approximately 60% of project duration
10	Duration of HVAC trade is approximately 65% of project duration
11	Once 10% of HVAC is complete, firefighting trade starts
12	Duration of firefighting trade is approximately 30% of project duration
13	Typically, once framing is complete, elevator and escalator trade starts
14	Duration of elevator and escalator trade is approximately 30% of project duration

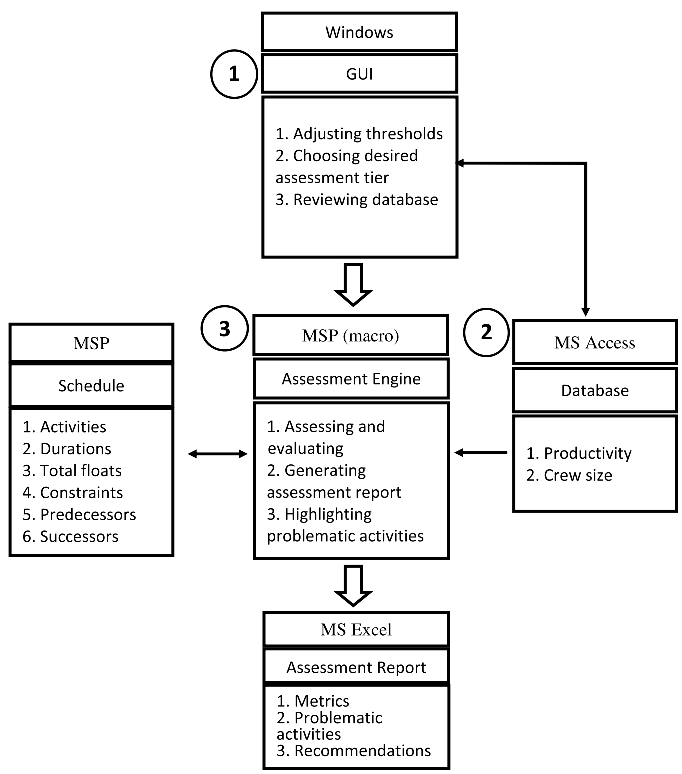

Fig. 4. SAE system architecture

overview of the suitability of the job logic of an educational project schedule (Moosavi 2012).

Computer Implementation

The developed method was automated in a software application called *Schedule Assessment and Evaluation* (SAE) (Moosavi 2012) to assist owners in reviewing and evaluating detailed schedules for building construction projects. SAE is a Windows-based system for assessing schedules that are developed based on the critical path method (CPM). SAE was coded using *Visual Basic* (VB) and performs three tiers of schedule assessment: (1) assessment of schedules against industry benchmarks, (2) job logic assessment of selected construction trades, and (3) assessment of productivity and crew size considered for a number of commonly used trades in building construction. SAE consists of three main modules: a user interface, coded using VB, to facilitate data entry; an assessment engine to evaluate schedules, which was coded using VB application (VBA) for *Microsoft Project* (MSP); and a database, developed using *Microsoft Access*, to house data pertinent to productivities and crew sizes. The architecture of SAE is presented in Fig. 4. The user interface is the part that allows the user to activate any of the three tiers of assessment and input the relevant data for each tier. The user also can use the interface to review and revise the database. The assessment engine is indeed a macro coded using VBA and embedded in a MSP environment. It is the core part of SAE that assesses schedules, generates evaluation reports, and highlights activities with faulty attributes. The database encompasses entities such as, for example, footings, walls, and columns and their related typical crew size, average productivity, and unit of measurement. The developed SAE can run on PCs equipped with MSP 2007. Thus, if a schedule is developed using other scheduling software, it should first be converted to MSP format.

In its first tier of assessment, SAE automatically calculates 14 quantitative schedule assessment metrics and compares the results to industry benchmarks (Moosavi 2012). These include the total number of activities, total number of critical activities, criticality rate (number of critical activities divided by total number of activities), near criticality rate (number of near critical activities divided

SAE (Schedule Assessment & Evaluation)

First Level Assessment and Evaluation Result

Project Name

General Information

Project duration = A
Total number of activities = B
Total number of critical activities = C
Maximum suggested activity duration = D
Total number of activities with out of range duration = E
Maximum suggested critical activity duration = F
Total number of critical activities with excessive duration = G
Total number of constraints = H
Total number of relationships = I
Relationship per activity = J
Number of open-ended activities = K
Standard deviation of activities duration = L
Criticality rate(duration of activities) = M
Criticality rate (number of activities) = N
Near criticality rate = O
Total number of activities with excessive total float = P
Total number of activities with negative total float = Q
This schedule is not loaded with resources
This schedule is not loaded with cost

Recommendations:

No open-ended activity is allowed. Link all open-ended activities to appropriate successor/predecessor

Detailed Information

Activities with out of range duration

Activity Name	Activity ID	Activity Duration(Days)
AAA	B	C

Critical activities with excessive duration

Activity Name	Activity ID	Activity Duration(Days)
DDD	E	F

Open-Ended Activities

Activity Name	Activity ID
HHH	J

Activities with excessive total float

Activity Name	Activity ID	Total Float (Days)
KKK	L	M

Activities with negative total float

Activity Name	Activity ID

Fig. 5. Typical report for first tier of assessment

Table 4. Case Examples

Description	Project A	Project B	Project C	Project D
Floors	17	15	4	3
Area (m^2)	68,000	33,000	6,000	7,000
Project value (million dollars)	172	120	20	—
Project duration (days)	1,028	543	295	344

by total number of activities), project cost ratio (cost associated with critical activities divided by total project cost), project effort ratio [critical path effort (number of labors) divided by total project effort], number of activities with out-of-range duration, number of critical activities with out-of-range duration, number of activities with out-of-range total float, activities with negative total float, open-ended activities (activities with no predecessor or successor), total number of constraints, total number of relationships, and relationships per activity. It is noteworthy to indicate that while the user can modify the float value that renders activities near critical, it was set at 10 days (O'Brien and Plotnick 2010) as a default value.

After conducting this level of assessment, SAE reports the calculated metrics and lists the activities with out-of-range attributes in the assessment report and highlights these activities directly on the schedule being evaluated. The software also presents a set of recommendations for corrective action based on the analysis performed. A typical report for the first tier of assessment is presented in Fig. 5.

The next level of assessment focuses on the job logic of schedules. For this purpose, a set of typical activities associated with reinforced concrete framing of building construction was incorporated into the developed software application, including typical relationships among them. These relationships are developed based on the sequence of work for a set of common activities in building construction. At this level of assessment, the assessment engine reads activity names and recognizes the defined keywords (e.g., *rebar*, which represents a rebar installation activity). Afterwards, actual relationships for recognized activities would be compared by the necessary predecessors and successors (e.g., rebar installation must be followed by pouring concrete). SAE highlights recognized activities that lack the necessary relationships. The name and identification (ID) of these activities are flagged in the output report along with their necessary predecessor or successor (Moosavi 2012).

The last tier of assessment is dedicated to reviewing the productivity and crew size for a set of commonly used trades in building construction and their impact on activity durations. For this purpose, a database is developed to house typical productivity rates and crew sizes extracted from RSMeans building construction cost data (RSMeans 2009). In conducting this tier of assessment, SAE compares planned productivities and crew sizes for selected activities to those stored in the developed database. If SAE finds any disagreement of more than 30%, the ID and name of related activities will be listed in the generated assessment report and highlighted directly on the schedule under review. It should be noted that the default value of 30% used here can be revised.

Case Examples

To demonstrate the use of the developed method and its computer application, schedules of four case examples, including three actual projects (Projects A, B, and C) and one hypothetical project (Project D), were analyzed. The three case examples were also assessed by the DCMA 14-Point method and the results compared. The three actual projects are three institutional buildings constructed for Concordia University in Montreal, Canada. These projects are buildings located in the two campuses of the University in Montreal. The hypothetical schedule is a built-in template provided by MSP 2007. This schedule was merely used to test the second and third tiers of schedule assessment, evaluating job logic and the rationale behind productivities and crew sizes. The characteristics of these projects are summarized in Table 4.

The schedules of the three real projects were assessed based on the developed method of schedule assessment and its software application, which is mainly concerned with quantitative evaluation criteria. These schedules were reviewed to determine the assessment provisions that they satisfy. At the end of the assessment process, the SDI (the total sum of weights of the satisfied provisions)

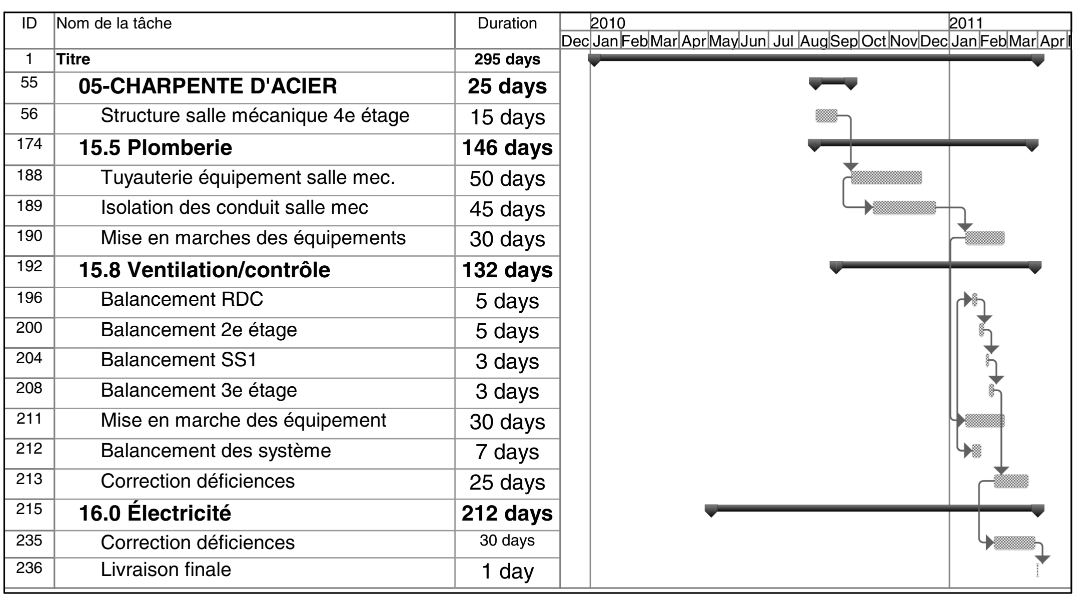

Fig. 6. Snapshot from analyzed critical path of Project C

Table 5. Comparison of Results

Schedule	Schedule A	Schedule B	Schedule C
Number of DCMA test passed	4	4	3
SDI (out of 1,000)	562	441	327

SDI = schedule development index; DCMA = Defense Contract Management Agency.

was calculated for each of the three cases. Schedule A obtained the highest SDI in comparison with the other two schedules. Schedule A received a SDI of 562 (out of 1,000), while Schedules B and C received 441 and 327, respectively (Moosavi 2012). There was a set of common deficiencies among the three cases. As a result, the schedules were unable to satisfy the criteria pertinent to Resource Loading, Responsibility Assignment, Trade's Peak Resource Loading, Peak to Average Labor Ratio, Duration of Critical Activities, Project Cost Ratio, Project Effort Ratio, Lag Duration, Open-Ended Activities, Activities Float, and others (Moosavi 2012). Thus, these schedules lost approximately 400 points. In addition, Schedules B and C were unable to satisfy Critical Path, Constraints, Permits and Environmental Remediation, Relationship Ratio, and Submittals Review criteria (Moosavi 2012). This is because those schedules were found to have excessive application of constraints, no inclusion of obtaining permits and review of submittals activities, and an abnormally high activity relationships ratio. Fig. 6 shows a snapshot depicting the analyzed critical path for Project C. The difference between the SDI of Projects B and C originated from four criteria that Schedule B satisfied to a greater degree than did Schedule C. These criteria were Minimum Milestones, Submittal Activities, Startup and Testing Activities, and Procurement Activities. The automated assessment was repeated three times for each schedule, and the results were consistent.

The actual schedules were also analyzed using the DCMA 14-Point Assessment. Schedules A and B passed four tests, whereas Schedule C passed only three tests (Moosavi 2012). The three cases were unable to pass the remaining tests designed for initial schedules because (1) there was a multitude of activities with lags in their dependencies, (2) there was a large number of "start-to-start" relationships between activities, (3) numerous activities had a high total float, and (4) the schedules were not loaded with resources. In addition, Schedule C had several activities with leads in their relationships and a multitude of open-ended activities (Moosavi 2012). The results of assessments are summarized in Table 5.

To test the second and third tiers of assessment, the hypothetical schedule was used since the actual projects were not developed at the required level of detail. Thirty schedule activities regarding concrete framing were subject to job logic assessment. To test the developed software application, the dependencies among 10 activities (out of 30 activities) were deliberately revised by deleting the necessary predecessors and successors (Moosavi 2012). For instance, the necessary relationships between form work activities and pour concrete activities were deleted. Then the automated job logic assessment was performed. The software was able to highlight the 10 activities with faulty job logic. The activities associated with the framing trade for the first and third floors were randomly selected to perform the third tier of assessment, which performs

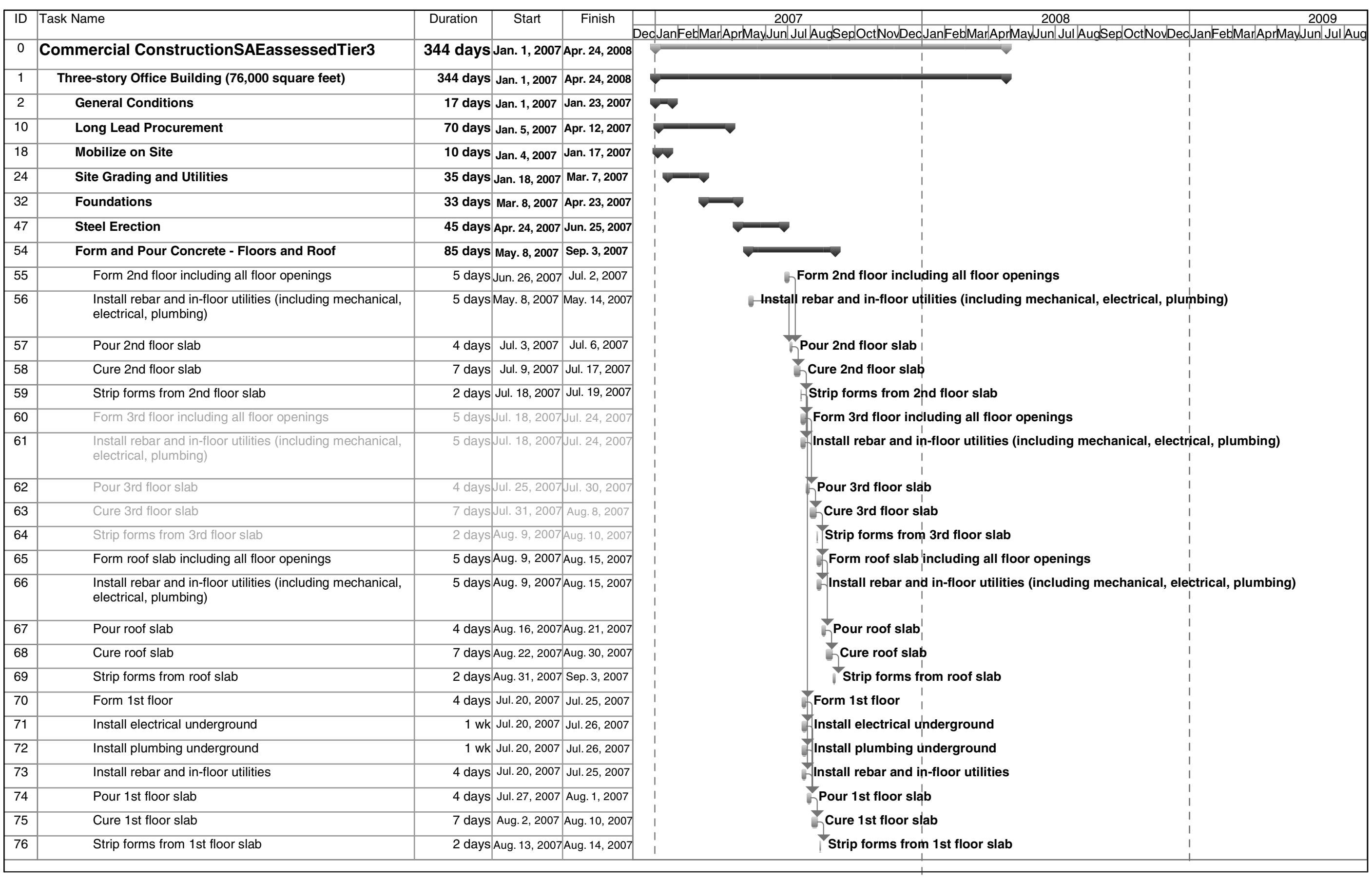

Fig. 7. Schedule D after third tier of assessment (activities with faulty attributes highlighted)

SAE (Schedule Assessment & Evaluation)

Productivity And Crew Size Assessment & Evaluation Result

Project Name: Office Building Construction.mpp

Activities With abnormal Crew Size or Duration

Crew size for activity:"60. Form 3rd floor including all floor openings" need to be reviewed as crew size should equal 6 laborers.

Productivity for activity: "60. Form 3rd floor including all floor openings" need to be reviewed as productivity should be approximately 320 SF Per Day.

Crew size for activity: "61. Install rebar and in-floor utilities (including mechanical, electrical, plumbing)" need to be reviewed as crew size should equal 4 6 laborers.

Productivity for activity: "61. Install rebar and in-floor utilities (including mechanical, electrical, plumbing)" need to be reviewed as productivity should be approximately 2.9 Ton Per Day.

Crew size for activity: "62. Pour 3rd floor slab " need to be reviewed as crew size should equal 9 6 laborers.

Productivity for activity: "62. Pour 3rd floor slab " need to be reviewed as productivity should be approximately 120 CY Per Day.

Crew size for activity: "63. Cure 3rd floor slab " need to be reviewed as crew size should equal 2 6 laborers.

Productivity for activity: "63. Cure 3rd floor slab " need to be reviewed as productivity should be approximately 55 CsF Per Day.

Crew size for activity: "64. Strip forms from 3rd floor slab " need to be reviewed as crew size should equal 4 6 laborers.

Productivity for activity: "64. Strip forms from 3rd floor slab " need to be reviewed as productivity should be approximately 170 SF Per Day.

Fig. 8. Report for third tier of assessment

productivity and crew size evaluation. The activities of the framing trade for the first floor were loaded with appropriate crew sizes based on typical industry productivity rates, and the activities for the third floor were loaded with incorrect values (Moosavi 2012). Upon performing the analysis, the software application identified the five activities with unreasonable attributes and highlighted them directly on the schedule, as shown in Fig. 7. In addition, these activities were listed in the output report, as shown in Fig. 8.

Discussion of Results

All three schedules suffered from a set of deficiencies. Their respective SDIs were considerably less than the perfect score of 1,000. Nevertheless, the SDIs calculated for Schedules A and B were relatively higher than that for Schedule C (Table 5), indicating that Schedules A and B were better developed than Schedule C. While reviewing the same three schedules using the DCMA 14-Point method, similar results were observed. Schedules A and B were able to pass more tests than Schedule C. This indicates that Schedules A and B are more mature in comparison to Schedule C.

Schedules A and B obtained different SDIs. However, they passed the same number of tests using the DCMA 14-Point Assessment method. The SDI indicates that Schedule A was able to fulfill the requirements of seven more criteria than Schedule B. Schedule A had a reasonable critical path, criticality rate, and phase overlap. Furthermore, this schedule included submittal review and obtaining permits activities. In addition, Schedule A had a reasonable number of constraints and relationship ratios. With the exception of the number of constraints, the DCMA method could not address these issues. Experts recommend consideration of these issues while reviewing schedules. This finding was observed when analyzing the results of the online questionnaire and is backed up by the literature (Moosavi 2012). In addition, the evaluation results obtained by the developed method were presented to the director in charge of the three projects to elicit his feedback on the developed method through a structured interview. There was complete agreement on the results generated, and he stated that the schedules could have been improved if they were free from the deficiencies detected by the developed method (Moosavi 2012).

Conclusion

A structured method for the review and evaluation of detailed schedules in building construction was presented. The method encompasses 48 schedule assessment criteria defined based on analyzing and synthesizing sporadic knowledge of schedule review published in textbooks, professional guidelines, dissertations, and articles. The defined criteria were augmented based on feedback received from experts through 20 sessions of structured interviews. The developed method aimed to present, not exhaustive criteria for schedule assessment, but rather a structured process that could be further enhanced and expanded upon. The presented method will assist owners in performing a structured review and effective schedule assessment and evaluation in order to make appropriate decisions regarding the submitted schedules. In addition, a composite index was introduced for the evaluation of the overall level of fitness for purpose of detailed schedules taking into account the relative level of importance of each schedule assessment criterion. The relative levels of importance of the criteria were defined based on the feedback collected from industry professionals via an online questionnaire. In addition, an empirical method was devised for a job logic review of schedules developed for the construction of multistory reinforced concrete institutional buildings based on an analysis of the historical data of recently completed projects. This method introduced a set of rules (thresholds) regarding the duration and start time of major construction trades in multistory institutional buildings.

The developed method of schedule assessment and evaluation was implemented in a software application to facilitate its use. The coded software application provides schedule assessment against industry-recommended practices. In addition, the software application evaluates the rationale of job logic and the reasonability of productivity and crew size for a set of commonly used activities in building construction. Furthermore, the software application provides users with a set of recommendations regarding the deficiencies identified. The method is flexible and could be used in different domains of construction. However, the defined thresholds in the empirical method for job logic review is applicable to the construction of reinforced concrete educational buildings, and those used in the assessment of productivities and crew sizes are applicable to building construction.

Schedules of three actual and one hypothetical project were analyzed using the developed method and its software application. The deficiencies identified were presented to an expert highly involved with the actual projects to elicit his feedback. There was agreement between the expert's assessment and those generated by the developed method and the expert believed that these schedules could be considered more reliable if they were free from the identified deficiencies. The actual case examples were also analyzed by means of another method of schedule review available. The results were compared and differences identified. The results of the analysis revealed that, whereas the other method is unable to distinguish well-developed schedules from poorly developed ones, the developed method can effectively evaluate schedules considering the related weights of each schedule assessment criterion.

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