

Schedule Quality Assessment for nD Models using Industry Foundation Classes

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Abstract –

Schedule assessment models were created to ensure the proper development of a schedule. The checks can be categorized into scheduling-related and constructability reviews. Most of the existing automated models are targeted towards two-dimensional schedules, and not nth-dimensional, despite the emergence of building information modelling in the construction industry. The type, method and relations between stored temporal information for activities in nth-dimensional models differ than the typical two-dimensional schedules. Accordingly, this paper presents the adaptation of the existing schedule quality assessment criteria to evaluate nth-dimensional models, utilizing building information modelling and Industry Foundation Classes (IFC). The paper starts with a comprehensive review of previous assessment models, identifying the major checks performed, detailing out the needed activity information and evaluation techniques. The checks are then categorized as quantifiable and qualitative, to differentiate between the measures that can be fully automated and others which would require expert intervention. Afterwards, the paper presents the methodology for attaining the inputs required for the quantitative measures in nD models. The methodology revolves around using IFC, as a standard data model for storing building and construction data. Accordingly, a technological review was conducted of the existing nD modelling software, to view the capabilities and limitations that could affect the development of a schedule assessment model. Initial Algorithms were developed to measure the wellness of schedule properties such as activity duration, criticality levels and accuracy of relationships. These developed algorithms were then verified by testing them versus different schedules with known errors.

Keywords –

4D Modelling; Schedule health assessment; Schedule quality checks; IFC

1 Introduction

According to International Building Information Modelling (BIM) Report 2017 by National BIM Standard, 78% of Canadians think that BIM is the future for managing project information and 67% are currently using BIM in their organization. [1]. The design and construction industry are now transitioning from use of two-dimensional Computer aided designs (CAD) and paper for design to three-dimensional digital models loaded with information. The BIM usage in project is expected to continue growing sharply in coming years [2]. The emergence of BIM in construction industry has allowed for the development of nD models, which combine the 3D spatial information with time, cost, resources, etc. The development of these models has provided enhanced multi-disciplinary and constructability analysis, and more efficient communication of spatial and temporal information between project teams by visualizing the evolution of the construction works throughout the project duration, allowing for the creation of more practical time schedules [3].

The United States Government Accountability Office (GAO) reports that there is a significant relationship between good scheduling practices used early in the project life cycle and the ultimate success of the project [4]. Accordingly, extensive research has been conducted to develop metrics that evaluate the quality of schedules, from various aspects, such as the construction logic, the activity identification, adequacy of estimates durations, enough allocation of resources, ideal cash flow distribution, etc. [5] [6] [7] [8]. Additionally, these metrics have been automated via commercial software [9] [10] [11] [12]. However, despite BIM's growing popularity, these automated schedule assessment models are still configured based upon the review of schedules from the conventional planning tools. In nD models the activities' temporal information and schedule relations are stored in a different database configuration than that in the conventional planning tools (such as Primavera &

Microsoft projects), which is more complex owing to combining the spatial information in the same database. Hence, the current automated schedule assessment models cannot be used to evaluate nD models without adaptation, which is rendering the process of development of these models inefficient.

Consequently, the focus of this paper is to develop the framework that adapts the current schedule assessment metrics of conventional planning tools, to capture information and analyse the schedules directly from nD models. Furthermore, the framework is based upon the Industry Foundation Classes (IFC) format, which is an open and neutral data format, to standardize the information storage and to work with any nD modelling software in the market. IFC is defined using the ISO 10303 suite of specifications for data modelling and exchange, also known as STEP (Standard for the Exchange of Product Data) [13]. This paper presents its method for categorizing previously developed evaluation metrics to identify the potential ones for adaptation. Then, the paper presents the methodology for capturing the selected metrics from nD databases in IFC format, and the corresponding algorithms using Psuedo code. Lastly, the paper verifies the approach via a theoretical case study of a 3-story office building, where faulty schedules were created intentionally to measure the responsiveness of the algorithms.

2 Review of Previous Schedule Assessment Models

The most popular assessment model is that of the United States Defence Contract Management Agency (DCMA). They formulated 14 points to assess the schedule quality at both pre-construction and during construction and identified the threshold for each which are presented in Table 1 [14]. For example, to test schedule practicality, they identified metrics as: (1) logic: which stated that only 5% of the activities in the schedule are allow to not have successors nor predecessors, to ensure proper linkage, (2) leads: which stated that activities cannot have a relationship between them with a negative lag, as this leads to improper relationships, (3) hard constraints: which stated that any schedule cannot have more than 5% of its activities with hard constraints, and they tend to disrupt the paths when being misplaced, etc. Currently, these points represent the minimum checks in modern assessment models, with variant thresholds.

Table 1. DCMA 14 Metrics [14]

Metric	Description	Threshold
Logic	Activities without successors/or predecessors	< 5%
Leads	Relationships that have a negative lag	0%
Lags	Relationships that have positive lags	< 5%
Relationship Types	Finish to Start Relationships	>= 90%
Hard Constraints	Activities with Must Finish On/ Must Start On/ Start No Later Than/ Finish No Later Than	< 5%
High Float	Activities with total float greater than 44 WD	< 5%
Negative Float	Activities with total float less than 0	0 %
High Durations	Activities with Duration greater than 44 WD	< 5%
Invalid Dates	Activities with forecast dates earlier than status date or actual dates later than status date	0 %
Resources	Activities without resource loading (money/ hours)	-
Missed Tasks	Activities with actual/forecasted finish dates later than planned finish date	< 5%
Critical Path Test	Test the integrity of the critical path by introducing intentional slippage. If the delay is not proportional to the slippage, then the logic is faulty and is flagged	
Critical Path Length Index (CPLI)	(Critical Path Length + Total Float) / Critical Path Length	>= 0.95

Baseline Execution Index (BEI)	Activities completed within current reporting period / (Activities completed in previous reporting periods + Activities missing their planned finish dates)	≥ 0.95
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Further metrics were developed in later work after the DCMA to add more analysis for areas as the logic and resources. [8] [15], developed their assessment model, which would check the job logic by: (1) Recognizing pre-defined keywords in the activities' names (2) check for the existence of relationships between each set of keywords. For example, any activity name containing "pouring" must have predecessors with activity names containing "framework" and "rebars", and successors with activity names containing "curing". Furthermore, they developed a set of empirical rules to verify the job logic in any schedule. The empirical rules explained the expected relationship and duration ratios that activities should have with reference to the schedule. For instance, the duration for the curtain wall activities should be around 30% of the project duration, and cannot start until at least 3 floors are done with the framing works. As for resource allocation, their model compared the schedule's productivity rates with that of RS Means, flagging any activities with a deviation of over 30%. Opposing to the DCMA, their system categorized the metrics as obligatory and complementary, where the former must be satisfied, and the later measures the fitness according to a "Schedule Development Index (SDI)". The schedule fitness was considered excellent with $SDI \geq 800$, good with $800 > SDI \geq 500$, and acceptable with $SDI < 500$.

[5] [6] [7] developed 75 schedule requirements grouped under 5 categories: (1) General Requirements: which dealt with generic parameters, such as checking for an activity coding structure, defined calendar, etc. (2) Construction Process Requirements: which dealt with job-logic, productivity, activity duration and timing. (3) Schedule mechanics requirements: which dealt with scheduling issues as open-ended activities or relationship types (4) Cost and resource requirements: which dealt with cost and resource loading assignments. (5) Control process requirements: which dealt with validating and evaluating the schedule updates. They used the BEI and CPLI of DCMA, which are shown above in Table 1. Their model was based on user-defined thresholds for each requirement, in which graphs would be developed to display a schedule's performance (rating) under each requirement group according to the defined thresholds, where the rating is a subjective evaluation of the reviewer. The main addition in their assessment model is identifying spatial requirements under "Construction Process requirements" as having a "safe and non-congested work areas." which was done manually.

Similarly, [3] [16] and [17], developed their assessment criteria by reviewing the 4D schedule model created in ArcGIS. However, contrary to the typical metrics, their model focused mainly on the review of the job logic by manual observation of the 4D visualization to check for the adequate activity detailing and proper sequencing. Also, their model ensured that all temporal activities were assigned to at least one spatial object, based their assessment criteria on the manual visualization of 4D schedule to ensure the sequencing and constructability. Such research was based on expert judgement, with loosely defined metrics and was never automated. Till date, there doesn't exist a comprehensive model that combines temporal and spatial metrics for assessing schedule qualities, as that would require moving between more than one software and migrating the data back and forth for multiple iterations which is time-consuming.

3 Model View Definitions for Industry Foundation Classes

IFC schema is constructed of entities (or classes), the relationship between entities, and attributes, which together constitute the IFC model. An IFC model is usually big as it is a representation of all physical and non-physical elements in the project for all types of information (spatial, temporal, etc.) [18]. There are 4 standard methodologies for understanding IFC: (1) ISO 16739 for data sharing in the construction and facility management (2) International Framework for Dictionaries (IFD) ISO 12006-3 (3) Information Delivery Manual (IDM) ISO 29481-1 ISO 29481-2, and (4) Model View Definition (MVD) buildingSMART [19].

Focusing on MVDs, they represent is a subsection of the IFC schema for specific use cases. Meaning that the use of MVDs allows for extracting the necessary information only from IFC and not dealing with the entire model. This allows for faster analysis and less computational efforts. For example, when analysing schedule quality, the required information from IFC is mostly temporal information, and the size and coordinates of the physical components, with no need of material, or structural information. An MVD can help filter this information from an IFC Model. The latest IFC Schema developed by buildingSMART is IFC4 Addendum 2 with two released MVDs: Reference View and Design Transfer View, where the later is more comprehensive than the former and both contain the schedule information [20].

4 Methodology

4.1 Database Creation

Figure 1 displays the 3 steps taken to develop the nD assessment model. Stage 1 deals with the compilation of previous literature, international standards and commercial tools to create a database of 176 metrics. Each metric was tagged to its author, provided with a clear description, displays the suggested threshold (if any).

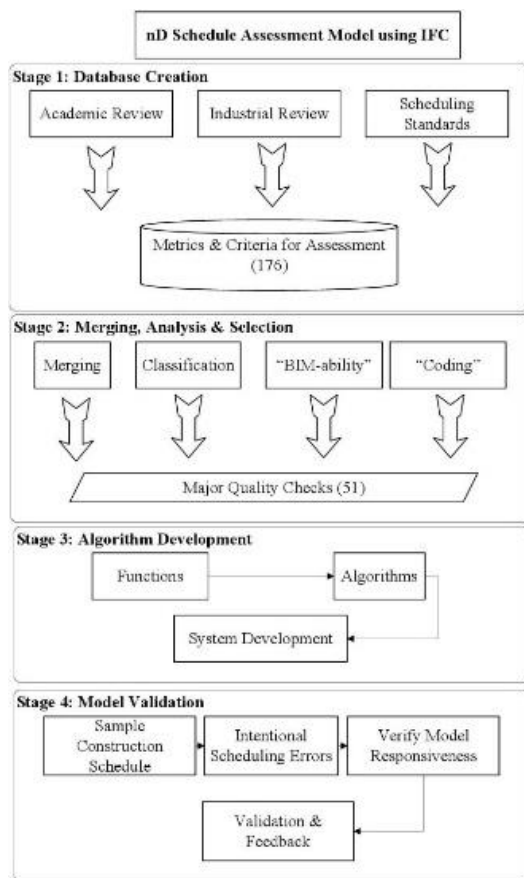


Figure 1. Methodology Procedure

4.2 Merging, Analysis & Selection

The second stage is the analysis of the database (176 metrics) which was conducted on 4 aspects: (1) Merging: to remove any duplicate checks that were suggested by more than one researcher, while maintaining the suggested threshold by each. For example, [14] suggested high duration activities metrics as shown in Table 1. This principle was also used by [8] and [7], but each defined a different threshold in their approaches. This reduced the metrics to 168. (2) Classifying the metrics as (2.1) qualitative: where 26 metrics had no clear

threshold defined, and their description indicated manual expert intervention; (2.2) quantitative: where 104 metrics had clear thresholds and evaluation criteria; and (2.3) generic metrics: where 38 of the metrics had very generic description and couldn't be analysed without additional information.

As the target is developing an automated system, the focus was on the quantitative metrics, having clear guidelines for evaluation, which had 83 related to the planning (pre-construction) phase, and 21 related to the progress monitoring (construction) phase. The paper's concentration was on the metrics for the pre-construction phase. Where these were selected for further analysis of their "BIM-ability": a check to verify the existence of the required information in a BIM model exported in an IFC formatted database; and "coding potential": the ability to capture the information using a suitable MVD. This eventually led to selecting 51 metrics for the nD schedule assessment model.

4.3 Algorithm Development

Some of the selected metric required the same information, with the difference of the evaluation criteria and threshold, and hence could use the same algorithm. For example, 2 of the metrics selected were "relationships with lag" and "relationships with lead". Both shared the same evaluation criteria shown in Equation 1, where the metric depended mainly on measuring the ratio between the number of relationships (links # (Lag or Lead)) that had a lag or a lead, to the total number of relationships (Total Links #). hence, both metrics required filtering part of the part of the links with lags or leads. The only difference is the selection, for "lead" links are negative lags and "lag" links are positive lags. Accordingly, both can use the same algorithm. Subsequently, 22 unique algorithms were developed for the 51 metrics. Furthermore, these algorithms shared some global functions that were created as well.

$$\text{Links \# (Lag or Lead) / Total Links \#} \quad (1)$$

To better explain this approach, Figures 2 and 3 shows the codes for the "total tasks" global function used in the "logic density" algorithm. The logic density is a measure of the soundness (practicality) of a schedule by finding the ratio of the number of relationships developed to the number of activities created. The threshold limit is a minimum of 2.1. To calculate this metric, the "number of links" and the "total number of activities" need to be captured. The "total number of activities" is also required in the "high-duration" metric, where the activities with a duration higher than a specified value are compared to the "total number of activities". The threshold for this measure is a maximum of 5%. Hence, a global function called "total tasks" was created to be used in both algorithms.

```

Total Tasks:

BEGIN FUNCTION TotalTasks(IfcTask,
IfcRelNests)
  "" INPUT: IfcTask.ID(),
    IfcRelNests.RelatingObject()
  OUTPUT: TotalTasks - A list containing all
    Tasks""

  DECLARE LIST: A, B, TotalTasks

  FOR EACH ID IN IfcTask
    ADD IfcTask.ID to List A
  END FOR

  FOR EACH IfcRelNests.RelatingObject[ID]
    ADD IfcRelNests.RelatingObject[ID] to List B
  END FOR

  TotalTasks = List A - List B

  RETURN TotalTasks
END
    
```

Figure 2 "Total Task" Global Function

```

Logic Density
Relationships per activity or Relationship ratio or
Logic Density = # of Logic links / # Total Tasks

BEGIN MAIN LogicDensity (IfcRelSequence,
AllowableValue = 2.1 )
  "" INPUT: IfcRelSequence.ID()
  DECLARE LIST: TotalTasks
  DECLARE NUMBER: TotalNumberOfTask = 0,
    LogicLinks = 0

  TotalTasks = CALL FUNCTION
  TotalTasks(IfcTask, IfcRelNests)
  TotalNumberOfTask = COUNT ID in
  TotalTasks
  TotalNumberOfTask = 100 *
  TotalNumberOfTask

  LogicLinks = COUNT ID in IfcRelSequence

  PRINT CALL FUNCTION
  MeasureCheck(Numerator: LogicLinks,
  Denominator: TotalNumberOfTask, value:
  AllowableValue, Condition: >, MetricName:
  "LogicDensity%=")
END
    
```

Figure 3. "Logic Density Algorithm"

5 Model Verification

As explained before, the developed algorithms were tested against a hypothetical case study of a 3-storey office building. The 3D model was created using Autodesk Revit. Then was imported to Synchro Pro to develop the nD model. The reason for selecting Synchro Pro over Autodesk Navisworks is because of its extra project management abilities, that enabled the storing of relationships between activities and the assigning of resources and cost loading. Additionally, Synchro Pro supports exporting nD models in IFC format [21].

A baseline schedule was developed for the model, then intentional scheduling errors were placed as alternative scenarios. An example of these errors is changing the activity duration of the foundation works to 60 working days (1,728,000 seconds) and setting the threshold for 44 working days (1,267,200 seconds). The verification was done by breaking down each algorithm into sub-sections and manually calculating the output of each section. Continuing with the "High duration" metric example, Figures 4, 5 and 6 show the breakdown of the algorithm. Step 1 (Figure 4) is to identify the attribute "ID" under "IfcScheduleTimeControl" Class with attribute "ScheduleDuration" greater than 1,267,200 seconds. The model filtered out the ID # 48719 and not # 48701 which was correct. As the # 48701 referred to a WBS level and not an activity. This output verified the functionality of the "Total Tasks" global function and the capturing process. Step 2 & 3 are to find the flagged activity's name, which is stored under "IfcTask" class. Hence, step 2 (Figure 5) is to find the "IfcTask" number under "RelatedObjects" attribute corresponding to the "IfcScheduleTimeControl ID" # 48719 under the "Time for Task" attribute in the "IfcRelAssignsTasks" Class. Lastly, step 3 (Figure 6) is to print out the "Name" attribute for the selected "ID" under "IfcTask" Class.

IfcScheduleTimeControl (41)			
ID	GlobalId	OwnerHistory	ScheduleDuration
48701	3NokVVgsH6aRUs2p\$5W5_4	IfcOwnerHistory 5	1814400
48710	3gC0\$XPQT7495FmP7p_\$Dq	IfcOwnerHistory 5	230400
48719	3MDQqkX_969PX5xnlX79sB	IfcOwnerHistory 5	1728000
48728	0mHop__Yj1OQGrytDRxwnR	IfcOwnerHistory 5	0.00E+00

Figure 4. "High Duration" Metric: Step 1 Output

IfcRelAssignsTasks (41)		
ID	RelatedObjects	TimeForTask
48708	(1) IfcTask 48700	IfcScheduleTimeControl 48701
48717	(1) IfcTask 48709	IfcScheduleTimeControl 48710
48726	(1) IfcTask 48718	IfcScheduleTimeControl 48719
48735	(1) IfcTask 48727	IfcScheduleTimeControl 48728

Figure 5. "High Duration" Metric: Step 2 Output

IfcTask (41)			
ID	Name	TaskId	Description
48700	Office building	1	1
48709	Sub-structure	1.1	1.1
48718	Foundation	1.1.1	1.1.1

Figure 6. "High Duration" Metric: Step 3 Output

6 Limitations & Challenges

Although the use of IFC format allowed for standardization independent from any software application, yet it has presented some challenges as well. The main challenge in this study was the lack of any existing software that exports nD models in IFC format other than Synchro Pro. Moreover, Synchro Pro is based upon IFC2x2 and IFC2x3, earlier schemas than IFC4 which are not as comprehensive as IFC4. Lastly, Synchro uses a specific MVD that does not export all resource and cost assignments and hence any algorithms related to such information could not be verified. Unfortunately, the industry does not have a nD modelling software that is based on IFC4 and can utilize any of the released MVDs.

Another challenge with the use of IFC was the different methodology and definition for certain temporal information. For example, the types of tasks available in IFC are attendance, construction, demolition, dismantle, disposal, installation, logistic, maintenance, move, operation, removal, renovation [22]. However, in Synchro Pro, the activity types were level of effort (LOE), resource dependent, and time dependent. The same applies for the definitions of the milestones. Accordingly, all metrics related to these two aspects could not be verified as well.

7 Conclusion & Future Works

The paper presents a novel schedule assessment model that can evaluate the quality of the construction schedule directly from nD models, without the need to revert to the conventional planning tools. The model starts with developing a database of the assessment criteria developed by previous researchers and commercial software. Then, the criteria were merged and analysed to determine the quantifiable metrics that can be automated. Afterwards, algorithms and global functions were developed to carry out the metrics. The model was then verified via a hypothetical case study of a 3-storey office building.

This work is a genuine contribution to the body of knowledge as it opens the door for the development of new assessment metrics by utilizing the nD abilities.

Hence, the future works will focus mainly on exploring such. Additionally, other future works would focus on enhancing the practicality of the developed assessment model such as (1) exploring the development of a specific MVD that would capture only the required information for assessment as the current MVDs have more information that is not used. (2) Extending the evaluation criteria to include controlling metrics that would evaluate the quality of the updated schedules. (3) validating the developed model against a real case study and receiving feedback.

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