A Knowledge Map for Delay Analysis Development

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Abstract
Schedule delays occur frequently in construction projects. There are many methodologies developed and used in the analysis and measurement of construction schedule delays. The popular and comparatively acceptable methodologies include the time impact method, the but-for technique and the windows method. However, no one method is accepted by all project participants and suitable for all situations. How to help the methodology user to select a suitable one or the researcher to develop new one is a critical issue in resolving delay claims. Several studies have provided tabular information for guiding users in selecting a suitable methodology. To provide additionally constructive information is required for new methodology development. A knowledge map is a vital tool for better knowledge management and learning. This study reviewed 28 articles regarding construction delay analysis techniques and then developed a knowledge map with a representation of cross-citation tree for delay analysis in the construction industry to represent methodology development. For novices interested in learning delay analysis knowledge, results of this study provide worthwhile information to know the key approaches and research trends. For researchers, results of this study provide a front-end research map for reference.

Keywords
Delay Analysis, Citation Analysis, Knowledge Map, Cross-citation Tree.

1. Introduction

Schedule delays occur frequently in construction projects. In 1989, Reams (1989) introduced a systematic approach to provide a procedure that shows detailed necessary to accurately analyze the delay effects. This approach may be the first introduced systematic method to quantify delay effects on contract parities, i.e. owner and contractor. After that, there are many methodologies developed and used in the analysis and measurement of construction schedule delays. The popular and comparatively acceptable methodologies include the time impact method, the collapsed as-built method and the window method. However, no one method is accepted by all project participants and suitable for all situations. To provide a comprehensive review on available delay analysis methodologies will advance the development of delay analysis. Although a knowledge map is a vital tool for better knowledge management and learning, this study employs the tool of knowledge map to represent the development of schedule delay analysis.

Although the articles with regarding to delay analysis appeared in conference proceedings, periodical journals or other types of reports, this study focused on the articles retrieved from periodical journals because of their accessibility. 35 methodologies appeared or discussed in 28 articles were investigated in this study. This study examined the presentation time of each methodology and then analyzed cross-citation among all methodologies. Based on the analysis results, this study developed a knowledge map

with a representation of cross-citation tree for delay analysis in the construction industry to represent knowledge development.

The investigated delay analysis approaches include:
1. Reams' Systematic Approach (Reams, 1989);
2. What-if (Schumacher, 1995);
3. But-for (or termed collapsing technique) (Schumacher, 1995);
4. Contemporaneous Period Analysis (or termed Windows Analysis) (Schumacher, 1995);
5. Global Impact Technique (Alkass *et al.*, 1995);
6. Net Impact Technique (Alkass *et al.*, 1995);
7. Adjusted As-built CPM Technique (Alkass *et al.*, 1995);
8. Snapshot Technique (Alkass *et al.*, 1995);
9. Time Impact Technique (or termed modified as-built) (Alkass *et al.*, 1995);
10. Isolated Delay Type (Alkass *et al.*, 1995);
11. Impacted Baseline Schedule (Zafar, 1996);
12. After-the-fact and Modified CPM Schedule (Zafar, 1996);
13. Dollar-to-time Relationship (Zafar, 1996);
14. Collapsed As-built Method (or termed As-built Less Delay Analysis) (Al-Saggat, 1998);
15. As-built Method (or termed As-planned vs. As-built) (Conlin and Retik, 1997);
16. As-planned Method (Conlin and Retik, 1997);
17. Affected Baseline Schedule (Al-Saggat, 1998);
18. Bar Chart Analysis (or termed As-built Bar Chart) (Bordoli and Baldwin, 1998);
19. Scatter Diagram (Bordoli and Baldwin, 1998);
20. As-built Network (Bordoli and Baldwin, 1998);
21. As-built Subtracting Impacts (Bordoli and Baldwin, 1998);
22. Baseline Adding Impacts (Bordoli and Baldwin, 1998);
23. B&B's Delay Analysis Method (Bordoli and Baldwin, 1998);
24. Modified As-built Method (Bubshait and Cunningham, 1998);
25. Impacted As-planned Method (or termed As-planned Plus Delay Analysis) (Stumpf, 2000);
26. CPM Update Review (Zack, 2000);
27. Linear Schedule Analysis (Zack, 2000);
28. Construction Delay Computation Method (Shi *et al.*, 2001);
29. Modified Windows Analysis (Gothand, 2003);
30. Impacted As-built CPM (Gothand, 2003);
31. New Isolated Delay Type (Kumaraswamy and Yogeswaran, 2003);
32. Apportionment Delay (Ng *et al.*, 2004);
33. Daily Windows Delay Analysis (Hegazy and Zhang, 2005);
34. Modified But-for Method (Mbabazi *et al.*, 2005);
35. Delay Section (Kim *et al.*, 2005).

2. Development Sequence of Delay Analysis Approach

Table 1 shows the identified delay analysis approaches found in reviewed journal articles. Some approaches are regarded as the same to others by certain researchers. This study tried to distinguish all independent approaches. All analysis approaches can be classified into two groups: source-unknown (in the citation column) and source-identified (in the development column). The approach listed in the source-unknown group means the original development cannot be found in reviewed articles. On the contrary, the approach in the source-identified group means its original can be identified.

Table 1: Delay Analysis Approach with Citation

No.	Approach	Development	Citation
1	Reams' Systematic Approach	Reams (1989)	Reams (1990)
2	What -if		Schumacher (1995), Al-Saggat (1998), Kim *et al.* (2005)
3	But-for		Schumacher (1995), Alkass *et al.* (1995), Zafar (1996), Al-Saggat (1998), Zack (2000, 2001), Brennan and D'Onofrio (2002), Lucas (2002), Gothand (2003), Kumaraswamy and Yogeswaran (2003), Lovejoy (2004), Ng *et al.* (2004), Kim *et al.* (2005)
4	Contemporaneous Period Analysis		Schumacher (1995), Alkass *et al.* (1995), Finke (1997), Al-Saggat (1998), Bordoli and Baldwin (1998), Finke (1999), Zack (2000), Stumpf (2000), Zack (2001), Brennan and D'Onofrio (2002), Lucas (2002), Lovejoy (2004), Hegazy and Zhang (2005), Kim *et al.* (2005)
5	Global Impact Technique		Alkass *et al.* (1995), Alkass *et al.* (1996), Gothand (2003), Kumaraswamy and Yogeswaran (2003), Scott *et al.* (2004), Ng *et al.* (2004)
6	Net impact Technique		Alkass et al. (1995), Alkass *et al.* (1996), Gothand (2003), Kumaraswamy and Yogeswaran (2003), Ng *et al.* (2004)
7	Adjusted As-built CPM Technique		Alkass *et al.* (1995), Alkass *et al.* (1996), Kumaraswamy and Yogeswaran (2003)
8	Snapshot Technique		Alkass *et al.* (1995), Alkass *et al.* (1996), Kumaraswamy and Yogeswaran (2003), Ng *et al.* (2004)
9	Time Impact Technique		Alkass *et al.* (1995), Riad *et al.* (1995), Alkass *et al.* (1996), Conlin and Retik (1997), Brennan and D'Onofrio (2002), Gothand (2003), Scott *et al.* (2004), Ng *et al.* (2004), Arditi and Pattanalitchamroon (2006)
10	Isolated Delay Type		Alkass *et al.* (1995), Bordoli and Baldwin (1998), Kumaraswamy and Yogeswaran (2003), Ng *et al.* (2004)
11	Impacted Baseline Schedule		Zafar (1996)
12	After-the-fact and Modified CPM Schedule		Zafar (1996)
13	Dollar-to-time Relationship		Zafar (1996)
14	Collapsed as-built Method		Al-Saggat (1998), Stumpf (2000), Gothand (2003), Lovejoy (2004)
15	As-built Method		Conlin and Retik (1997), Abdulaziz and Michael (1998), Zack (2000, 2001), Stumpf (2000), Brennan and D'Onofrio (2002), Lovejoy (2004), Arditi and Pattanalitchamroon (2006)
16	As-planned Method		Conlin and Retik (1997), Bubshait and Cunningham (1998), Gothand (2003)
17	Affected Baseline Schedule		Al-Saggat (1998)
18	Bar Chart Analysis		Bordoli and Baldwin (1998), Zack (2000, 2001)
19	Scatter Diagram		Bordoli and Baldwin (1998)
20	As-built Network		Bordoli and Baldwin (1998), Scott *et al.* (2004)
21	As-built Subtracting Impacts		Bordoli and Baldwin (1998)
22	Baseline Adding Impacts		Bordoli and Baldwin (1998), Scott *et al.* (2004)
23	B&B's Delay Analysis Method	Bordoli and Baldwin (1998)	
24	Modified As-built Method		Bubshait and Cunningham (1998)
25	Impacted As-planned Method		Stumpf (2000), Zack (2001), Brennan and D'Onofrio (2002), Lovejoy (2004), Arditi and Pattanalitchamroon (2006)
26	CPM Update Review		Zack (2000, 2001), Brennan and D'Onofrio (2002)
27	Linear Schedule Analysis		Zack (2000, 2001)
28	Construction Delay Computation Method	Shi *et al.* (2001)	
29	Modified Windows Analysis	Gothand (2003)	
30	Impacted As-built CPM		Gothand (2003)
31	New Isolated Delay Type	Kumaraswamy and Yogeswaran (2003)	
32	Apportionment Delay		Ng *et al.* (2004)
33	Daily Windows	Hegazy and Zhang (2005)	
34	Modified But-for Method	Mbabazi *et al.* (2005)	
35	Delay Section	Kim *et al.* (2005)	

Owing to some delay analysis approaches cannot be found in periodical journals, this study evaluated last approaches that can be clearly identified in journal articles. Table 2 shows the source-identified approaches with development sequence. It is clear that novel delay analysis methodologies emerged after 2000.

Table 2: Development Sequence of Source-identified Delay Analysis Approach

No.	Delay Analysis Approach	Year																	
		1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
1	Reams' Systematic Approach	1																	
2	What-if																		
3	But-for																		
4	Contemporaneous Period Analysis																		
5	Global Impact Technoque																		
6	Net Impact Technique																		
7	Adjusted As-built CPM Technique																		
8	SnapshotTechnique																		
9	Time Tmpact Technique																		
10	Isolated Delay Type																		
11	Impacted Baseline Schedule																		
12	After-the-fact and Modified CPM Schedule																		
13	Dollar-to-time Relationship																		
14	Collapsed As-built Method																		
15	As-built Method																		
16	As-planned Method																		
17	Affected Baseline Schedule																		
18	Bar Chart Analysis																		
19	Scatter Diagram																		
20	As-built Network																		
21	As-built Subtracting Impacts																		
22	Baseline Adding Impacts																		
23	B&B's Delay Analysis Method									1									
24	Modified As-built Method																		
25	Impacted As-planned Method																		
26	CPM Update Review																		
27	Linear Schedule Analysis																		
28	Construction Delay Computation Method													1					
29	Modified Windows Analysis															1			
30	Impacted As-built CPM																		
31	New Isolated Delay Type															1			
32	Apportionment Delay																		
33	Daily Windows																	1	
34	Modified But-for Method																	1	
35	Delay Section																	1	

3. Discussion Time

For identifying which delay analysis approach is the most popular one among all approaches, this study accumulates the discussion times in all reviewed articles. Table 3 shows the results of the accumulation for all approaches. As information shown in Table3, the years of 1996, 1998, 2000, 2003 and 2004 have discussion times over 10. Furthermore, the popular delay analysis approaches as shown in Table 3 include: But-for, Windows Analysis (Contemporaneous Period Analysis), and Time Impact Technique which have been discussed over 10 times.

Table 3: Discussion Time of Delay Analysis Approach

No.	Delay Analysis Approach	Year																			Total
		1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	
1	Reams' Systematic Approach		1	1																	2
2	What-if								1			2		2					1		6
3	But-for								1	2		2		1	1	1	1	1	2		12
4	Contemporaneous Period Analysis								1		1	2	1	2	1	2		1	2		13
5	Global Impact Technoque									1							2	2			5
6	Net Impact Technique								1	1							2	1			5
7	Adjusted As-built CPM Technique									1	1						1				3
8	Snapshot Technique								1	1							1	1			4
9	Time Impact Technique								2	1	1	1				1	2	2		1	11
10	Isolated Delay Type								1	1		1					1	1			5
11	Impacted Baseline Schedule									1											1
12	After-the-fact and Modified CPM Schedule									1											1
13	Dollar-to-time Relationship									1											1
14	Collapsed As-built Method									1		1		1		1	1	1		1	7
15	As-built Method										1	1		2	1			1		1	7
16	As-planned Method										1	1					1				3
17	Affected Baseline Schedule											1									1
18	Bar Chart Analysis											1		1	1						3
19	Scatter Diagram											1									1
20	As-built Network											1									1
21	As-built Subtracting Impacts											1									1
22	Baseline Adding Impacts											1									1
23	B&B's Delay Analysis Method											1									1
24	Modified As-built Method											1									1
25	Impacted As-planned Method													1	1	1		1		1	5
26	CPM Update Review													1	1			1			3
27	Linear Schedule Analysis													1	1						2
28	Construction Delay Computation Method														1						1
29	Modified Windows Analysis																1				1
30	Impacted As-Built CPM																1				1
31	New Isolated Delay Type																1				1
32	Apportionment Delay																	1			1
33	Daily Windows																		1		1
34	Modified But-for Method																		1		1
35	Delay Section																		1		1
	Total	0	1	1	0	0	0	0	8	12	5	19	1	12	8	6	15	14	8	4	

4.Citation Times and Knowledge Map Develpment

Citation means that a short note recognizing a source of information or of a quoted passage. For the articles published in any periodical journal, the literature review in articles almost gives an observation about related studies. Citation usually appears in the literature review. This study analyzed the citation times from the source-identified approaches to all approaches. Table 4 shows the citation analysis results. For the approach whose original publication source has been identified, three approaches (B&B's Delay Analysis Method, Modified Windows Analysis and New Isolated Delay Type) have received much attention.

Although the number of citation times is various for different approach, the close related references will be identified by this analysis. Based on the results of citation analysis, this study developed a draft knowledge map that represents the connections between all delay analysis approaches. Figure 1 shows the knowledge map for delay analysis methodology development. From this knowledge map by cross-citation tree, users can identify the used schedule type (as-planned, as-built or both) and its correlations between all approaches for each approach.

Table 4: Citation Times of Identified Delay Analysis Approach

No.	Citation Approach	Development Approach								Total
		Reams' Systematic Approach	B&B's Delay Analysis Method	Construction Delay Computation Method	Modified Windows Analysis	New Isolated Delay Type	Daily Windows	Modified But-for Method	Delay Section	
1	Reams' Systematic Approach									0
2	What-if		1						1	2
3	But-for		1		1	1			1	4
4	Contemporaneous Period Analysis		1				1		1	3
5	Global Impact Technoque				1	1				2
6	Net Impact Technique				1	1				2
7	Adjusted As-built CPM Technique					1				1
8	Snapshot Technique					1				1
9	Time Tmpact Technique				1	1				2
10	Isolated Delay Type		1							1
11	Impacted Baseline Schedule									0
12	After-the-fact and Modified CPM Schedule									0
13	Dollar-to-time Relationship									0
14	Collapsed As-built Method				1					1
15	As-built Method									0
16	As-planned Method				1					1
17	Affected Baseline Schedule									0
18	Bar Chart Analysis		1							1
19	Scatter Diagram		1							1
20	As-built Network									0
21	As-built Subtracting Impacts									0
22	Baseline Adding Impacts									0
23	B&B's Delay Analysis Method									0
24	Modified As-built Method									0
25	Impacted As-planned Method									0
26	CPM Update Review									0
27	Linear Schedule Analysis									0
28	Construction Delay Computation Method									0
29	Modified Windows Analysis									0
30	Impacted As-Built CPM				1					1
31	New Isolated Delay Type									0
32	Apportionment Delay									0
33	Daily Windows									0
34	Modified But-for Method									0
35	Delay Section									0
	Total	0	6	0	7	6	1	0	3	

5. Conclusions and further research

Providing a comprehensive review on available delay analysis methodologies will advance the development of delay analysis approaches. This study employed the tool of knowledge map, a vital tool for better knowledge management and learning, to represent the development of schedule delay analysis approaches. Excluding the articles from conference proceedings or other reports, this study analyzed the articles from periodical journals with investigations on delay analysis methodology development and discussion. This study analyzed delay analysis approaches in the aspects of development chronology and cross citation among all approaches. Study results reveal following findings. (1) There are at least 35 approaches been developed from 1989. (2) The most cited approaches are the But-for, Windows Analysis (Contemporaneous Period Analysis), and Time Impact Technique approaches. (3) For the source-identified delay analysis approach, B&B's Delay Analysis Method, Modified Windows Analysis and New Isolated Delay Type are the most cited approaches.
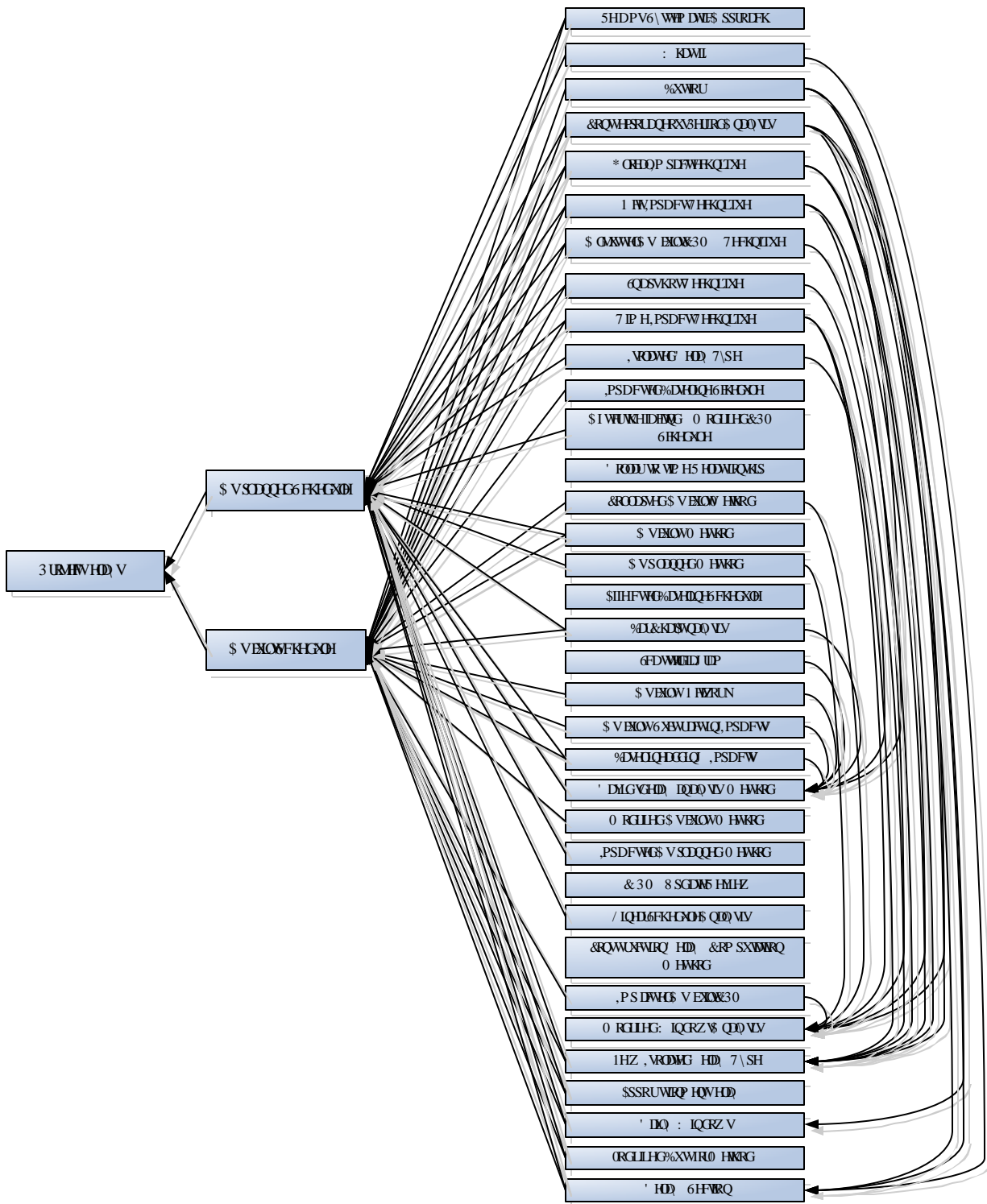
Figure 1: Knowledge Map for Delay Analysis Methodology Development

Furthermore, a knowledge map for delay analysis methodology development is established to represent the cross-citation of identified novel delay analysis approaches. For novices interested in learning delay analysis knowledge, results of this study provide worthwhile information to know the key approaches and research trends of delay analysis. For researchers, results of this study provide a front-end research map for reference in developing new approach.

Although the source for knowledge map development is limited on the articles from periodical journals, the analysis procedures and preliminary results are valuable for further investigation. A complete study on all referred articles including periodical journals, conference proceedings or other reports will be executed shortly.

6. Acknowledgements

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