

Table S1: Factors affecting cash flow in the construction projects

No.	Name of the factor	Related Studies	Frequency	Rank
1	Delays in payments from client	(Le et al., 2020), (Zayed & Liu, 2014), (Adjei et al., 2018), (Omopariola et al., 2020), (Ikediashi & Okolie, 2020), (Odeyinka et al., 2008), (Odeyinka & Lowe, 2001), (Odeyinka & Lowe, 2000), (Khosrowshahi, 2000), (Abd El Razek et al., 2014), (Mbachu, 2011), (Muhammad et al., 2018), (Khanzadi et al., 2017)	13	1
2	Lending interest of rates	(Le et al., 2020), (Zayed & Liu, 2014), (Joseph Buerter, 2010), (Omopariola et al., 2020), (Omopariola et al., 2020), (Ikediashi & Okolie, 2020), (Odeyinka et al., 2008), (Ojo, 2012), (Odeyinka & Lowe, 2000), (Khosrowshahi, 2000), (Muhammad et al., 2018)	11	2
3	Rate of inflation	(Ikediashi & Okolie, 2020), (Le et al., 2020), (Odeyinka et al., 2008), (Edwards et al., 2017), (Ojo, 2012), (Odeyinka & Lowe, 2000), (Odeyinka & Lowe, 2001), (Abd El Razek et al., 2014), (Muhammad et al., 2018), (Khanzadi et al., 2017)	10	3
4	Estimating strategies	(Zayed & Liu, 2014), (Joseph Buerter, 2010), (Ikediashi & Okolie, 2020), (Odeyinka et al., 2008), (Odeyinka & Lowe, 2001), (Odeyinka & Lowe, 2000), (Abd El Razek et al., 2014), (Mbachu, 2011), (Muhammad et al., 2018)	9	4
5	Percent of retention	(Le et al., 2020), (Zayed & Liu, 2014), (Joseph Buerter, 2010), (Adjei et al., 2018), (Ikediashi & Okolie, 2020), (Odeyinka & Lowe, 2000), (Abd El Razek et al., 2014), (Muhammad et al., 2018),	8	5
6	Claims	(Le et al., 2020), (Zayed & Liu, 2014), (Adjei et al., 2018), (Ikediashi & Okolie, 2020), (Odeyinka et al., 2008), (Ojo, 2012), (Mbachu, 2011), (Muhammad et al., 2018)	8	5
7	Under work measurement	(Le et al., 2020), (Zayed & Liu, 2014), (Joseph Buerter, 2010), (Adjei et al., 2018), (Muhammad et al., 2018), (Khosrowshahi, 2000), (Edwards et al., 2017)	8	5
8	Contractual payment terms	(Le et al., 2020), (Zayed & Liu, 2014), (Joseph Buerter, 2010), (Adjei et al., 2018), (Adjei et al., 2018), (Mbachu, 2011), (Ojo, 2012), (Khanzadi et al., 2017)	8	5
9	Over Work measurement	(Le et al., 2020), (Zayed & Liu, 2014), (Joseph Buerter, 2010), (Adjei et al., 2018), (Muhammad et al., 2018), (Ojo, 2012)	6	6
10	Inability to manage variation of works	(Zayed & Liu, 2014), (Adjei et al., 2018), (Ikediashi & Okolie, 2020), (Odeyinka et al., 2008), (Ojo, 2012), (Muhammad et al., 2018)	6	6
11	Work execution errors	(Le et al., 2020), (Zayed & Liu, 2014), (Adjei et al., 2018), (Odeyinka & Lowe, 2001), (Odeyinka & Lowe, 2000), (Muhammad et al., 2018)	6	6
12	Decision to sub-contract	(Zayed & Liu, 2014), (Adjei et al., 2018), (Odeyinka et al., 2008), (Khosrowshahi, 2000), (Mbachu, 2011), (Khanzadi et al., 2017)	6	6
13	Cost of Materials	(Le et al., 2020), (Zayed & Liu, 2014), (Adjei et al., 2018), (Ikediashi & Okolie, 2020), (Odeyinka et al., 2008),	5	13

Table S1 (continued)

No.	Name of the factor	Related Studies	Frequency	Rank
14	Delayed Payment for Suppliers	(Le et al., 2020), (Zayed & Liu, 2014), (Adjei et al., 2018), (Omopariola et al., 2020), (Khosrowshahi, 2000)	5	13
15	Inclement weather	(Zayed & Liu, 2014), (Odeyinka et al., 2008), (Odeyinka & Lowe, 2001), (Odeyinka & Lowe, 2000), (Muhammad et al., 2018)	5	13
16	Fraudulent practices by employees	(Edwards et al., 2017), (Omopariola et al., 2020), (Abd El Razek et al., 2014), (Muhammad et al., 2018), (Ikediashi & Okolie, 2020)	5	13
17	Difficulty in loan accessibility from financiers	(Omopariola et al., 2020), (Edwards et al., 2017), (Odeyinka et al., 2008), (Ojo, 2012), (Khanzadi et al., 2017)	5	13
18	Number of projects held by one contractor	(Joseph Buerter, 2010), (Adjei et al., 2018), (Omopariola et al., 2020), (Mbachu, 2011), (Edwards et al., 2017)	5	13
19	Advance Payment	(Le et al., 2020), (Zayed & Liu, 2014), (Joseph Buerter, 2010), (Adjei et al., 2018)	4	19
20	Time of releasing retention	(Le et al., 2020), (Zayed & Liu, 2014), (Adjei et al., 2018), (Odeyinka et al., 2008)	4	19
21	Lack of regular Cash flow forecasting	(Edwards et al., 2017), (Zayed & Liu, 2014), (Joseph Buerter, 2010), (Khosrowshahi, 2000)	4	19
22	Project Delayed	(Zayed & Liu, 2014), (Joseph Buerter, 2010), (Ikediashi & Okolie, 2020), (Ojo, 2012)	4	19
23	Replacement of defective work	(Zayed & Liu, 2014), (Adjei et al., 2018), (Ikediashi & Okolie, 2020), (Mbachu, 2011)	4	19
24	Client insolvency	(Edwards et al., 2017), (Odeyinka et al., 2008), (Mbachu, 2011), (Khanzadi et al., 2017)	4	19
25	Government policies	(Ikediashi & Okolie, 2020), (Ojo, 2012), (Muhammad et al., 2018), (Khanzadi et al., 2017)	4	19
26	Disputes between contractors and owners	(Zayed & Liu, 2014), (Mbachu, 2011), (Muhammad et al., 2018), (Khanzadi et al., 2017)	4	19
27	Design errors and omissions	(Ikediashi & Okolie, 2020), (Zayed & Liu, 2014), (Khanzadi et al., 2017), (Mbachu, 2011)	4	19
28	Delay in delivery of the materials	(Ikediashi & Okolie, 2020), (Zayed & Liu, 2014), (Muhammad et al., 2018), (Ojo, 2012)	4	19
29	Changes in currency exchange rate	(Abd El Razek et al., 2014), (Odeyinka & Lowe, 2000), (Odeyinka & Lowe, 2001), (Ojo, 2012)	4	19
30	Plan and Equipment Costs	(Le et al., 2020), (Adjei et al., 2018), (Odeyinka et al., 2008), (Abd El Razek et al., 2014)	4	19
31	Loan payment	(Le et al., 2020), (Zayed & Liu, 2014), (Adjei et al., 2018)	3	31
32	Withholding Tax	(Le et al., 2020), (Joseph Buerter, 2010), (Adjei et al., 2018)	3	31
33	Wages of labor and staff	(Le et al., 2020), (Zayed & Liu, 2014), (Adjei et al., 2018)	3	31
34	Delay in paying creditors	(Joseph Buerter, 2010), (Adjei et al., 2018), (Muhammad et al., 2018)	3	31
35	High overheads	(Joseph Buerter, 2010), (Adjei et al., 2018), (Edwards et al., 2017)	3	31
36	Poor site management	(Zayed & Liu, 2014), (Khanzadi et al., 2017), (Joseph Buerter, 2010)	3	31
37	Complexity of work	(Ikediashi & Okolie, 2020), (Khanzadi et al., 2017), (Ojo, 2012)	3	31
38	Contractor's lack of resources	(Ikediashi & Okolie, 2020), (Mbachu, 2011), (Zayed & Liu, 2014)	3	31
39	Technological communications	(Le et al., 2020), (Zayed & Liu, 2014)	2	39
40	Contractor's pricing strategy (front end loading or back end loading)	(Joseph Buerter, 2010), (Muhammad et al., 2018)	2	39

Table S2: Types of the uncertainties integrated with cash flow and the used methods

No.	Document	Types of uncertainties	Optimization tools	Simulation models	BIM and other technologies	Artificial intelligence	Hybrid methodologies	Other Methodologies
1	(Elghaish et al., 2021)	The lag between accomplishing activities by the contractors and issuing payments by the owner			An integration between 4D and 5D BIM models within the IPD system			
2	(Türkakin et al., 2020)	The absence of schedules updates in smaller projects		Monte Carlo Simulation model				
3	(Mirnezami et al., 2020)	The uncertainties in activities durations due to the overlapping of activities				DSM model with AQM technique under a type-2 fuzzy environment		
4	(Ali Mirnezami et al., 2020)	The uncertainties in durations qualities and costs of the activities						TODIM method and CCM method under Grey system theory
5	(Tabei et al., 2019)	Uncertainty in projects start date, activities' durations, material and resources cost, the amount of money being issued by the owner, and date of owner's payment				Fuzzy approach		
6	(Tavakolan & Nikoukar, 2019)	The uncertainty in the resource utilization, which may cause a shift in the start time of the activities	A hybrid SFL-GA algorithm					
7	(Andalib et al., 2018)	The time interval between the contractor expenses and owner repayment		Monte Carlo Simulation model				
8	(Mohagheghi et al., 2017)	The lack of sufficient knowledge of activities' durations and cost						
9	(Ning et al., 2017)	Uncertainty in activities durations	Multi-objective metaheuristic optimization model					

Table S2 (continued)

No.	Document	Types of uncertainties	Optimization tools	Simulation models	BIM and other technologies	Artificial intelligence	Hybrid methodologies	Other Methodologies
10	(Yu et al., 2017)	The imprecise duration that is formed due to overlapping activities				Fuzzy DSM method		
11	(El-Abbasy et al., 2016)	Allocation and leveling of resources procedures when dealing with multiple projects	Multi-Objective Scheduling Optimization using Evolutionary Algorithm (MOSCOPEA)					
12	(Tabyang & Benjaoran, 2016)	The lag between sub-contractors requests for payments and the actual payments						Modifying the traditional FBS model, which is called MFBS
13	(Lu et al., 2016)	Lag between accomplishing work by the contractor and actual payments by the owner			A 5D BIM model			
14	(Wei & Yun, 2015)	Sales prices, rental prices, public matching facilities, and Derivation (owner perspective)		A simulation model based on Beta and normal distributions				
15	(Gajpal & Elazouni, 2015)	The lag between accomplishing activities by the contractors and issuing payments by the owner.						A polynomial shifting algorithm to specify activities' start times.
16	(Han et al., 2014)	Risks related to exchange rates, Cost escalation, the geotechnical conditions, and weather conditions		A Monte Carlo simulation method				
17	(Maravas & Pantouvakis, 2012)	Cost and duration uncertainties.				Fuzzy approach generating S-surfaces instead of S-curves		
18	(Kishore et al., 2011)	The risk in changing portfolio composition for a construction firm when dealing with multiple projects.				Fuzzy Systems Theory		
19	(Elazouni, 2009)	The uncertainty in the Schedule when it is subjected to cash constraints in multiple projects environment						A heuristic algorithm That consider all the possible schedules and ranks them

Table S2 (continued)

No.	Document	Types of uncertainties	Optimization tools	Simulation models	BIM and other technologies	Artificial intelligence	Hybrid methodologies	Other Methodologies
20	(Cheng et al., 2009)	Not specified				Four types of AI techniques were used: K-means, Fuzzy logic, Neural networks, and GA		
21	(Elazouni & Metwally, 2007)	The uncertainty in resource availability in construction projects					Implementation of GA prototype and was coded using Visual Basic	
22	(Hegazy & Ersahin, 2001)	Resources constraints integrated with schedules					A spreadsheet model that integrates CPM With TCT and the model was optimized using GA	
23	(Barbosa & Pimentel, 2001)	Delay in financial transactions, delays of owner's payments, and budget constraints					Linear programming is integrated with an optimization model to achieve a greater profitability	
24	(Ibrahim, 2010)	The problems that emerged due to the human inputs, which can be lengthy and cause delays.			A computer model using Visual Basic.Net is derived to capture the data from the site, integrated with the cash flow forecasting model			

BIM: Building Information Modeling, DSM: Dependency Structure Matrix, AQM: Alternative Queuing Method, TODIM: The Interactive Multi-Criteria Decision Making, CCM: Critical Chain Management, GA: Genetic Algorithm, FBS: Finance Based Scheduling, IPD: Integrated Project Delivery, TCT: Time and Cost Trad-Off, CPM: Critical Path Metho, SFL: Shuffled Frog Leaping

Table S3: The addressed areas in capital structure management of cash flow analysis

	Document	Contractors' Perspective	Owner's perspective	Main objectives	Used Methods
1	(Cevikcan & Kose, 2020)		✓	Estimate the fitting space allocation of residential projects in terms of profitability and liquidity.	Two mixed-integer linear programming model.
2	(Alavipour & Arditi, 2018)	✓		Develop a financial model that considers financing alternatives in terms of sources and times.	A CPM scheduling model was integrated with an optimization model developed by MATLAB
3	(Etemadi et al., 2018)		✓	Determine the most profitable portfolio of projects and the optimal resources to do so.	A fuzzy analytic hierarchy process is employed
4	(Al-Shihabi & AlDurgam, 2017)	✓		Evaluate the Credit Line (CL) constrain, which the contractor should not exceed.	An optimization model called Max-Min ant system (MMAS) integrated with integer programming model.
5	(Jiang, 2012)	✓		Maximize the final capital structure of the contractor by negotiating the contract's terms with the owners and finding the optimal loan arrangement in the pre-tender stage.	An optimization model runs on Microsoft's Excel sheets
6	(Chen & Chen, 2012)	✓		Investigate the factoring financing mechanism in construction as a method to lower financing costs for the contractor.	A mathematical model
7	(Jiang, Issa, et al., 2011)	✓		Manage cash flow in the tendering and construction stages, considering the constraints in the financial market.	Pareto optimality network model
8	(Jiang, Malek, et al., 2011)	✓		Allocate the available capital structure to markets when dealing with a set of constraints.	A liner programming model
9	(Fathi & Afshar, 2010)	✓		Select the most appropriate line of credit option as a funding resource that ensures steady liquidity for the contractors.	An optimization model called multi-objective elitist Non-dominated Sorting Genetic Algorithm (NSGA-II).
10	(Chen et al., 2009)	✓		Maintain the most suitable cash balance for ongoing projects so that the construction firm could have a healthy cash flow.	A T-S fuzzy model was integrated with Miller and Orr method to implement a fuzzy S-curve regression model.
11	(Tang & Leung, 2009)		✓	Determine the best timing to invest in new projects as well as the best credit choice.	A fuzzy logic model integrated with AGA optimization model.
12	(Tang et al., 2006)	✓		Enhance the borrowing decision-making in a multi-project environment and select the most convenient funding schemes for the contractors.	A fuzzy reasoning technique integrated with AGA approach.

13	(Elazouni & Metwally, 2005)	✓	Control the required credit limits by minimizing the project duration and hence minimize indirect costs/maximize profits.	GA as an optimization model to select the optimal schedule that develops debit values below the credit limits
14	(Kaka & Price, 1994)	✓	Investigate the contractors' practices in financial budgeting.	A questionnaire survey (based on interviews) of 15 British construction companies.

Section S1: Other Topics related to construction cash flow

Apart from using cash flow analysis to calculate the required cash in every stage of the construction project, cash flow analysis can be used to determine other attributes. Hence, this category contains the articles that used cash flow analysis as an indicator in the decision-making processes. Therefore, this category mostly deals with the clients' perspectives and how cash flow assists them through the decision-making criteria for different purposes. The considered attributes in this category are as follows: 1) contractors' selection by the owners (Huang et al., 2014; Huang et al., 2013); 2) subcontractors' selection by general contractors (Elazouni & Metwally, 2000); 3) determining projects profitability for the owners (Akca et al., 2017; Hosny et al., 2012; Kern & Formoso, 2006; Kim et al., 2017); 4) selection of the most appropriate construction methods (Hegazy & Petzold, 2003); 5) assessment of contractors' bidding decisions (Biruk et al., 2017; Su & Lucko, 2015). *Table iv* illustrates the different areas of this category and the methods used to address them. As shown in *Table iv*, most of the cash flow analysis presented in this section is used as an indicator in the decision-making criteria. It is also noticeable that the most used techniques in this category are simulation techniques. The following paragraphs will discuss in-depth the use of cash flow in determining these different attributes.

Table S4: studies that addressed cash flow analysis as an indicator to evaluate other areas

	Document	Contractors' Perspective	Owner's perspective	Main objectives	Used Methods
1	(Elazouni & Metwally, 2000)	✓		To evaluate the decision criteria upon subcontracting some of the contractors' works	Linear programming module
2	(Hegazy & Petzold, 2003)	✓		To select the most appropriate construction method for each activity.	An optimization model using GA
3	(Wibowo & Kochendörfer, 2005)		✓	To evaluate the major uncertainties integrated with the infrastructure investments	A Latin Hypercube simulation model followed by sensitivity analysis
4	(Cheah & Liu, 2006)		✓	To assist the client in evaluating different options, which are integrated with several risk factors, upon investing in infrastructure projects	Monte-Carlo simulation model followed by a sensitivity analysis of the available options
5	(Huang et al., 2013)		✓	Prequalifying the contractors by assessing their financial capacity to select the most capable one	A simulation model based on Excel software
6	(Huang et al., 2014)		✓	To assess the financial stability and the credit quality for the contractors as a part of the prequalifying process	A dynamic threshold cash flow model (DCFM)
7	(Su & Lucko, 2015)	✓		To investigate the cash flow analysis under unbalanced bidding scenarios in order to select the optimal scenario	Singularity functions to drive a synthetic cash flow model
8	(Sharifi & Bagherpour, 2016)		✓	To assist managers in determining the profits according to the level of risk aversion	Simulation technique based on Variance-covariance matrix to estimate the profitability according to the risk factors
9	(Biruk et al., 2017)	✓		To provide a decision support system that can assist contractors in evaluating different bidding scenarios in the tender stage	Two linear programming models: one to calculate the total price; the other one to distribute the price between different items
10	(Pogorelov et al., 2018)		✓	To provide the potential investors with valuable financial information about the construction companies' cash flows	A direct method to estimate future cash flow based on companies' financial reports
11	(Anysz & Rogala, 2019)	✓		To evaluate the contract's terms that guarantee desirable profits for the contractors	A sensitivity analysis was conducted to show how payment terms impact cash demand and the NPV

12	(Hosny et al., 2012)	✓	To develop a decision support system to assess the expected profits of their planned projects considering the buyer behavior and the market complexity	A Monte-Carlo simulation model to examine the variety of methods of the buyer's payment
13	(Mohammad Mahdi Farshchian et al., 2017)	✓	To optimize the owner's profitability by examining different budget allocations scenarios in a multi-project environment	Agent-based simulation model
14	(Akçay et al., 2017)	✓	To examine the effects of risk factors on the hydropower investments, considering cash flow in the construction and operation stages.	A questionnaire survey followed by Monte-carlo simulation model
15	(Kim et al., 2017)	✓	To determine the optimal investment timing in the decision-making criteria	Real Options Evaluation (ROV) technique

Prequalifying a contractor is a method that many researchers have used to determine the contractor's capabilities and competence needed to contribute to the project bidding ([Huang et al., 2014](#)). The prequalification process is determined based on several aspects, including financial stability, past experiences, technical abilities, etc. However, the contractor's financial stability is the most vital factor addressed by the researchers in the contractors' selection criteria. Huang et al. (2014) employed a dynamic threshold cash flow model (DCFM) to evaluate the contractors' financial stability. Their study stated that cash flow is an ideal indicator for the contractor's prequalification. The study used the (DCFM) technique to calculate a quality score for each contractor according to their creditworthiness. The results showed that the closer these scores to zero indicate better creditworthiness, while those close to one refer to poor liquidity for the applied contractors. Similarly, Huang et al. (2013) stated that cash flow data for contractors reflect their abilities and financial capacities. The study simulated the future cash flow for construction firms using Excel software with Basic programming language. However, one drawback of this study is that the developed model relies

on standard and poor (S&B) ratings, which may not be obtainable when trying to assess other unrated construction firms.

Similar to the above selection technique, Elazouni and Metwally (2000) investigated the decision criteria upon subcontracting some of the contractors' works. Their study aimed to minimize the total project cost to the contractor by providing a decision support system that helps contractors make decisions regarding sublet some of their required activities to subcontractors. In order to achieve these objectives, the study employed a linear programming module. Another addressed aspect in this category is the evaluation of bidding scenarios for contractors using cash flow analysis. Regarding that matter, Biruk et al. (2017) aimed to analyze the contractors' invitations to tender by quantitatively assessing the feasibility of new contracts. The study implemented two linear programming models, which were used to calculate the total project cost and maximize the contractors' cash flow by optimizing the distribution of the bid amount among required activities. Su and Lucko (2015) investigated the cash flow analysis under unbalanced bidding scenarios, i.e., distributing the markup unevenly to ensure acquiring more cash in the initial stages of the projects (Cattell et al., 2007). The study employed singularity functions to drive a synthetic cash flow model that considers the markup as a function of time to address various unbalance bidding scenarios. However, some drawbacks of the study can be summarized as follows: it was assumed that the cost of any activity was evenly distributed over its duration; the study did not address the unbalanced scenarios that emerge from the individual rate loading, such as varying the prices of some activities that the client underestimated their quantity.

Furthermore, in this category, several authors have addressed how cash flow can assist the clients through investing decisions. For instance, M. M. Farshchian et al. (2017) aimed to optimize the owner's profitability by examining different budget allocations scenarios in a multi-project environment. Agent-based simulation modeling was used in this study to determine the availability of cash in different scenarios, including canceling, dealing, or

suspending some projects in the portfolio. Another simulation technique was addressed by Hosny et al. (2012) by employing a Monte-Carlo simulation model to examine the various methods of the buyer's payments as well as the market complexity, using cash flow as an indicator. However, the model relied on the user perspective of the property appreciation and the expected mark-up value. Monte-Carlo simulation was also used by Akcay et al. (2017) to address the impact of several risk factors on the profitability of hydropower investments, considering the cash flow of the construction and operation period. A questionnaire survey was carried out in this study to rate the impact of these risk factors on each cash flow parameter. Further investment evaluation was carried out by Kim et al. (2017) by employing the Real Options Evaluation (ROV) technique, which was influenced by the variations in the cash inflow/outflow of the projects. However, the study studied the impact of each profitability factor separately, while the correlation of these various factors could obtain more realistic results. The final application of cash flow analysis in this category was addressed by Hegazy and Petzold (2003). Their study adopted a genetic algorithms model to evaluate different construction methods that varied from lengthy and cheap to costly and short. Cash flow, among other indicators, was used to choose the most appropriate construction method for each activity during execution.

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